Pd-Catalyzed Coupling of β–Hydroxy α–Diazocarbonyl Compounds with Aryl Iodides: A Migratory Insertion/β-Hydroxy Elimination Sequence

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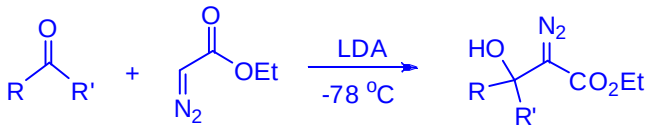
General All reactions were performed under a nitrogen atmosphere in a flame-dried reaction flask. All solvents were distilled prior to use. THF and toluene were dried over Na before use. For chromatography, 200-300 mesh silica gel (Qingdao, China) was employed. ^{1}H NMR and ^{13}CNMR spectra were recorded on Varian 300 or Brucker ARX 400 spectrometer in $CDCl_3$ solution and the chemical shifts were reported in parts per million (d) relative to internal standard TMS (0 ppm). Unless otherwise noted, materials obtained from commercial suppliers were used without further purification.

General Procedure for the Preparation of Ethyl 2-Diazo-3-hydroxy Carboxylates.[1]



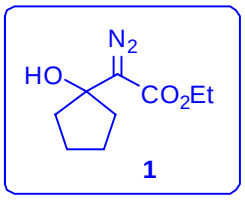
A cold (-10 °C) solution of lithium diisopropylamide [prepared by the addition of *n*-butyllithium in hexane (10 mL of a 2.5 M solution) to a solution of diisopropylamine (2.5 g) in THF (15 mL)] was added during 30 min to a stirred solution of the appropriate ketone (20 mmol) and ethyl diazoacetate (20 mmol) at -78 °C. The mixture was allowed to stir at -78 °C for 2 h, at which time the reaction was quenched with a saturated NH_4Cl solution and extracted with ether. The combined organic extracts were washed with saturated aqueous $NaHCO_3$ solution and brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude residue was subjected to flash silica gel chromatography to afford the pure ethyl 2-diazo-3-hydroxy carboxylate.

General Procedure for the Pd-Catalyzed Reactions

$Pd_2(dba)_3$ (2.5 mol%, 11.3 mg), 2-(dicyclohexylphosphino)-2',4',6'-triisopropylbiphenyl (Xphos, 10 mol%, 23.7 mg) and aryl iodide (0.6 mmol) were suspended in THF (3 mL) in a 10 mL Schlenk tube under nitrogen. Then diisopropylamine (0.22 mL, 1.5 mmol) and α–hydroxyl diazo compound (0.5 mmol) were added. The resulting solution was stirred at 70 ^{o}C for 24 h. After cooling to room temperature, the resulting mixture was filtered through a short path of silica gel, eluting with ethyl acetate. The volatile compounds were removed *in vacuo* and the crude residue was purified by column chromatography (SiO_2, hexane).

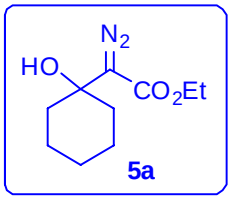
Spectral Data

Ethyl 2-Diazo-2-(1-hydroxycyclopenty1)acetate (1)[1]



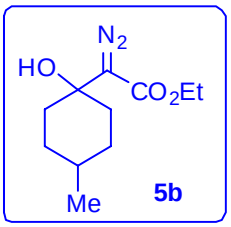
IR (neat) 3460, 2967, 2089, 1697, 1370, 1301, 1108, 750 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.25 (t, J = 7.2 Hz, 3H), 1.67-1.92 (m, 6H), 2.01-2.09 (m, 2H), 3.26 (s, 1H), 4.25 (q, J = 7.2 Hz, 2H).

Ethyl 2-Diazo-2-(1-hydroxycyclohexyl)acetate (5a)[2]



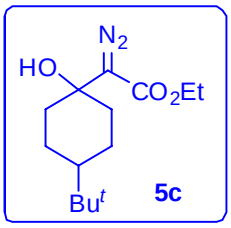
IR (neat) 3468, 2972, 2091, 1695, 1374, 4, 1109, 752 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.27 (t, J = 7.2 Hz, 3H), 1.32-1.90 (m, 10H), 3.32 (s, 1 H), 4.26 (q, J = 7.2 Hz, 2H).

Ethyl 2-Diazo-2-(1-hydroxy-4-methylcyclohexyl)acetate (5b)



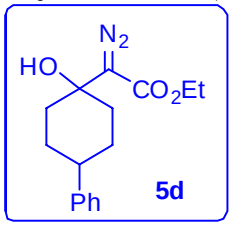
IR (neat) 3483, 2926, 2088, 1673, 1370, 1297, 1114, 1079, 744 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.93 (d, J = 5.6 Hz, 3H), 1.28 (t, J = 7.2 Hz, 3H), 1.40-1.69 (m, 7H), 2.04-2.07 (m, 2H), 3.47 (s, 1H), 4.23 (q, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.5, 22.2, 29.8, 31.9, 36.1, 60.8, 69.1, 167.5.

Ethyl 2-(4-*tert*-butyl-1-hydroxycyclohexyl)-2-diazoacetate (5c)



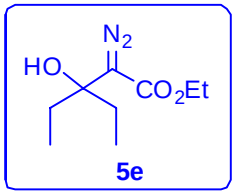
IR (neat) 2949, 2868, 2087, 1681, 1366, 1291, 1084, 747 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 0.83 (s, 9H), 0.89-1.06 (m,3H), 1.27 (t, J = 7.2 Hz, 3H), 1.50-1.60 (m, 2H), 1.69-1.74 (m, 2H), 2.24-2.29 (m, 2H), 3.51 (s, 1H), 4.22 (q, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.25, 14.28, 24.2, 27.3, 27.4, 32.0, 36.9, 46.8, 60.6, 71.8, 166.9.

Ethyl 2-Diazo-2-(1-hydroxy-4-phenylcyclohexyl)acetate (5d)



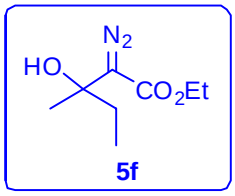
IR (neat) 3477, 2933, 2088, 1686, 1368, 1302, 1099, 746, 700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.30 (t, J = 7.2 Hz, 3H), 1.57-1.78 (m, 4H), 1.97-2.03 (m, 2H), 2.20-2.23 (m, 2H), 2.51-2.57 (m, 1H), 3.59 (s, 1H), 4.26 (q, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.6, 28.9, 36.6, 43.7, 61.0, 68.9, 126.2, 127.0, 128.5, 146.7, 167.5.

Ethyl 2-Diazo-3-ethyl-3-hydroxypentanoate (5e)



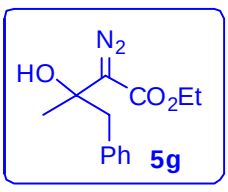
IR (neat) 3368, 2977, 2094, 1671, 1370, 1310, 1085, 1048, 908, 734 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.94 (t, J = 7.2 Hz, 6H), 1.29 (t, J = 7.2 Hz, 3H), 1.75 (t, J = 7.2 Hz, 4H), 3.83 (s, 1H), 4.22 (q, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 8.1, 14.5, 31.5, 60.9, 74.0, 167.8.

Ethyl 2-Diazo-3-hydroxy-3-methylpentanoate (5f)[3]



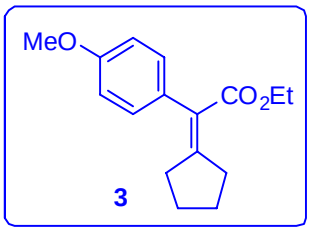
IR (neat) 3473, 2977, 2091, 1673, 1370, 1307, 1081, 745 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.94 (t, J = 7.2 Hz, 3H), 1.29 (t, J = 7.2 Hz, 3H), 1.68 (s, 3H), 1.76-1.88 (m, 2H), 3.79 (s, 1H), 4.25 (q, J = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 8.8, 14.5, 25.2, 34.5, 60.9, 71.6, 167.5.

Ethyl 2-Diazo-3-hydroxy-3-phenylbutanoate (5g)



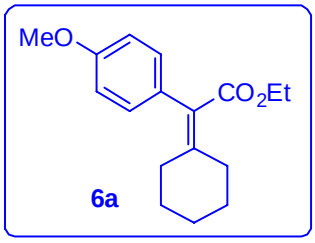
IR (neat) 3324, 2974, 2362, 2090, 1676, 1307, 1049, 731 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.21 (t, J = 7.2 Hz, 3H), 1.70 (s, 3H), 4.18 (q, J = 7.2 Hz, 2H), 4.35 (s, 1H), 7.25-7.34 (m, 3H), 7.47-7.49 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.4, 29.2, 61.1, 73.3, 124.7, 127.7, 128.5, 146.3, 167.0.

Ethyl 2-Cyclopentylidene-2-(4-methoxyphenyl)acetate (3)



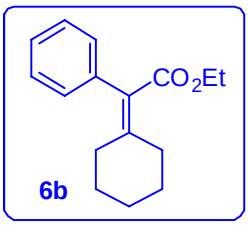
IR (film) 2952, 1705, 1608, 1511, 1245, 1206, 1038, 834 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.21 (t, J = 7.2 Hz, 3H), 1.57-1.62 (m, 2H), 1.72-1.79 (m, 2H), 2.21 (t, J = 7.2 Hz, 2H), 2.84 (t, J = 7.2 Hz, 2H), 3.81 (s, 3H), 4.15 (q, J = 7.2 Hz, 2H), 6.86 (d, J = 8.6 Hz, 2H), 7.08 (d, J = 8.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.5, 26.0, 26.9, 34.1, 35.4, 55.3, 60.2, 113.5, 125.4, 130.5, 131.6, 158.4, 162.4, 167.9; MS (70 eV) *m/z* (%) 260 (100) (M^+), 231(25), 214(66), 203(9), 185(94), 171(19), 159(23); HRMS (ESI) calcd for $C_{16}H_{21}O_3$ [$(M+H)^+$] 261.1485, found: 261.1484.

Ethyl 2-Cyclohexylidene-2-(4-methoxyphenyl)acetate (6a)



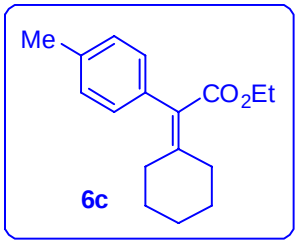
IR (film) 2930, 2854, 1711, 1607, 1509, 1261, 1244, 1188, 1033, 836 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.22 (t, J = 7.2 Hz, 3H), 1.54-1.69 (m, 6H), 2.01 (t, J = 6.2 Hz, 2H), 2.48 (t, J = 6.2 Hz, 2H), 3.79 (s, 3H), 4.16 (q, J = 7.2 Hz, 2H), 6.86 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 26.5, 28.32, 28.36, 32.0, 32.8, 55.3, 60.5, 113.6, 127.3, 129.8, 130.6, 148.3, 158.6, 169.7; MS (70 eV) *m/z* (%): 274 (100) (M^+), 245(11), 228(87), 217(11), 199(89), 184(19), 171(29), 159(24); HRMS (ESI) calcd for $C_{17}H_{23}O_3$ [$(M+H)^+$] 275.1641, found: 275.1644.

Ethyl 2-Cyclohexylidene-2-phenylacetate (6b)



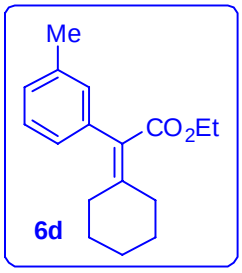
IR (film) 2927, 2854, 1712, 1510, 1448, 1260, 1188, 1035, 732 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.22 (t, J = 7.2 Hz, 3H), 1.54-1.72 (m, 6H), 2.08 (t, J = 6.2 Hz, 2H), 2.52 (t, J = 6.2 Hz, 2H), 4.16 (q, J = 7.2 Hz, 2H), 7.19-7.34 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 26.3, 28.22, 28.25, 32.0, 32.6, 60.4, 126.9, 127.6, 128.0, 129.4, 137.4, 148.9, 169.2; MS (70 eV) *m/z* (%): 244 (100) (M^+), 229(12), 212(91), 183(64), 169(36), 155(36); HRMS (ESI) calcd for $C_{16}H_{21}O_2$ [$(M+H)^+$] 245.1536, found: 245.1529.

Ethyl 2-Cyclohexylidene-2-p-tolylacetate (6c)



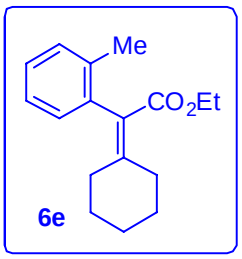
IR (film) 2928, 2854, 1712, 1444, 1260, 1218, 1187, 1106, 1037, 919, 773, 700 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.23 (t, J = 7.2 Hz, 3H), 1.56-1.74 (m, 6H), 2.12 (t, J = 6.2 Hz, 2H), 2.36 (s, 3H), 2.51 (t, J = 6.2 Hz, 2H), 4.18 (q, J = 7.2 Hz, 2H), 7.10-7.17 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 21.1, 26.4, 28.20, 28.23, 31.9, 32.6, 60.4, 127.5, 128.8, 129.2, 134.4, 136.5, 148.3, 169.4; MS (70 eV) *m/z* (%): 258 (100) (M^+), 229(12), 212(91), 183(64), 169(36), 155(36); HRMS (ESI) calcd for $C_{17}H_{23}O_2$ [$(M+H)^+$] 259.1692, found: 259.1687.

Ethyl 2-Cyclohexylidene-2-m-tolylacetate (6d)



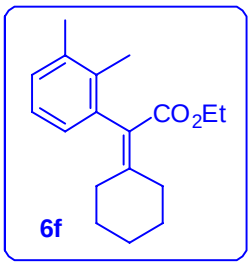
IR (film) 2927, 2855, 1713, 1447, 1261, 1203, 1037, 732 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.22 (t, J = 7.2 Hz, 3H), 1.54-1.71 (m, 6H), 2.09 (t, J = 6.4 Hz, 2H), 2.33 (s, 3H), 2.48 (t, J = 6.4 Hz, 2H), 4.16 (q, J = 7.2 Hz, 2H), 6.99-7.26 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 21.4, 26.4, 28.22, 28.26, 32.0, 32.7, 60.4, 126.4, 127.7, 127.8, 127.9, 137.2, 137.6, 148.2, 169.4; MS (70 eV) *m/z* (%): 258 (92) (M^+), 229(12), 212(100), 203(9), 183(54), 169(46), 155(35); HRMS (ESI) calcd. for $C_{17}H_{23}O_2$ [$(M+H)^+$] 259.1692, found: 259.1687.

Ethyl 2-Cyclohexylidene-2-o-tolylacetate (6e)



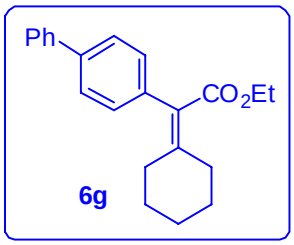
IR (film) 2928, 2855, 1709, 1448, 1261, 1200, 1184, 1104, 1035, 909, 733 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.19 (t, J = 7.2 Hz, 3H), 1.52-1.74 (m, 6H), 1.89-1.93 (m, 2H), 2.23 (s, 3H), 2.66-2.70 (m, 2H), 4.14 (q, J = 7.2 Hz, 2H), 7.08-7.20 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 19.7, 26.4, 28.0, 28.2, 31.9, 32.6, 60.1, 125.4, 126.3, 127.1, 129.6, 129.8, 136.8, 137.6, 151.6, 168.4; MS (70 eV) *m/z* (%) 258(100) (M^+), 229(7), 212(61), 183(56), 169(22), 155(25); HRMS (ESI) calcd for $C_{17}H_{23}O_2$ [$(M+H)^+$] 259.1692, found: 259.1686.

Ethyl 2-Cyclohexylidene-2-(2,3-dimethylphenyl)acetate (6f)



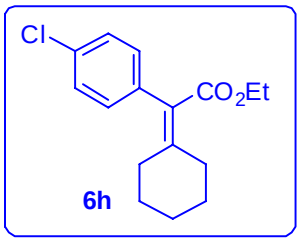
IR (film) 2927, 2854, 1710, 1448, 1262, 1198, 1094, 1033, 764, 731 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.14 (t, J = 7.2 Hz, 3H), 1.43-1.69 (m, 6H), 1.82-1.86 (m, 2H), 2.09 (s, 3H), 2.24 (s, 3H), 2.58-2.61 (m, 2H), 4.07 (q, J = 7.2 Hz, 2H), 6.89-7.02 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 16.3, 20.5, 26.4, 27.9, 28.3, 32.0, 32.5, 60.2, 125.1, 126.9, 127.6, 128.7, 135.4, 136.6, 137.6, 150.7, 168.7; MS (70 eV) *m/z* (%): 272 (100) (M^+), 257(5), 243(6), 226(86), 211(10), 197(45), 183(41), 169(19), 155(42); HRMS (ESI) calcd for $C_{18}H_{25}O_2$ [$(M+H)^+$] 273.1849, found: 273.1845.

Ethyl 2-(Biphenyl-4-yl)-2-cyclohexylideneacetate (6g)



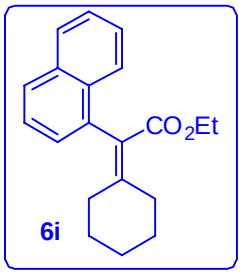
IR (film) 2929, 2854, 1714, 1485, 1447, 1264, 1186, 1034, 759, 733, 697 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.20 (t, J = 7.2 Hz, 3H), 1.53-1.87 (m, 6H), 2.11 (t, J = 6.4 Hz, 2H), 2.49 (t, J = 6.4 Hz, 2H), 4.15 (q, J = 7.2 Hz, 2H), 7.21-7.31 (m, 3H), 7.37-7.41 (m, 2H), 7.51-7.57 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 26.4, 27.5, 28.2, 32.1, 32.7, 60.5, 126.8, 127.0, 127.2, 127.3, 128.7, 129.8, 136.4, 139.7, 140.8, 149.0, 169.3; MS (70 eV) *m/z* (%): 320 (100) (M^+), 291(8), 274(88), 245(46), 231(11), 217(35), 205(23), 191(25), 178(21), 165(27), 152(15); HRMS (ESI) calcd for $C_{22}H_{25}O_2$ [$(M+H)^+$] 321.1849, found: 321.1844.

Ethyl 2-(4-Chlorophenyl)-2-cyclohexylideneacetate (6h)



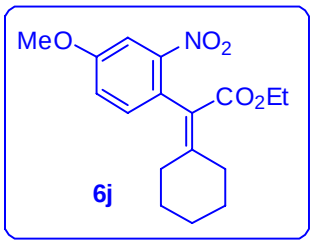
IR (film) 2929, 2854, 1712, 1448, 1260, 1188, 1035, 732 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.21 (t, J = 7.2 Hz, 3H), 1.53-1.71 (m, 6H), 2.05 (t, J = 6.4 Hz, 2H), 2.53 (t, J = 6.4 Hz, 2H), 4.15 (q, J = 7.2 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H), 7.29 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 26.3, 28.2, 32.2, 32.5, 60.5, 126.5, 128.3, 130.8, 132.9, 136.0, 150.4, 168.7; MS (70 eV) *m/z* (%): 278 (76) (M^+), 249(15), 232(100), 203(39), 191(6), 182(12), 169(67), 153(15); HRMS (ESI) calcd for $C_{16}H_{20}ClO_2$ [$(M+H)^+$] 279.1146, found: 279.1139.

Ethyl 2-Cyclohexylidene-2-(naphthalen-1-yl)acetate (6i)



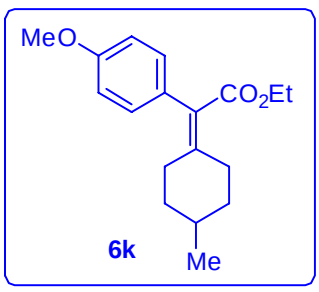
IR (film) 2929, 2854, 1709, 1532, 1263, 1199, 1091, 1031, 779 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.04 (t, J = 7.2 Hz, 3H), 1.39-1.42 (m, 2H), 1.53-1.56 (m, 2H), 1.72-1.85 (m, 4H), 2.68-2.75 (m, 2H), 4.03 (q, J = 7.2 Hz, 2H), 7.27-7.29 (m, 1H), 7.39-7.43 (m, 3H), 7.74-7.90 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 26.4, 28.2, 28.4, 32.2, 32.9, 60.3, 125.2, 125.3, 125.6, 125.7, 125.9, 127.2, 127.5, 128.1, 132.5, 133.6, 135.7, 152.8, 168.7; MS (70 eV) *m/z* (%): 294(100) (M^+), 265(19), 248(81), 219(73), 205(20), 191(58), 178(57), 165(65), 153(35); HRMS (ESI) calcd for $C_{20}H_{23}O_2$ [$(M+H)^+$] 295.1692, found: 295.1687.

Ethyl 2-Cyclohexylidene-2-(4-methoxy-2-nitrophenyl)acetate (6j)



IR (film) 2927, 2853, 1712, 1617, 1531, 1352, 1263, 1191, 1035, 733 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.24 (t, J = 7.2 Hz, 3H), 1.56-1.71 (m, 6H), 2.07 (t, J = 6.0 Hz, 2H), 2.58 (t, J = 6.0 Hz, 2H), 3.97 (s, 3H), 4.16 (q, J = 7.2 Hz, 2H), 7.05 (d, J = 8.4 Hz 1H), 7.37 (dd, J = 8.4, 1.6 Hz, 1H), 7.70 (d, J = 2.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 26.3, 28.3, 32.6, 56.6, 60.8, 113.2, 125.1, 126.9, 130.2, 135.5, 139.3, 152.0, 152.5, 168.4; MS (70 eV) *m/z* (%) 319 (13) (M^+), 302(100), 285(3), 273(23), 256(6), 244(8), 228(18), 210(10), 199(28), 184(7), 169(12), 153(10); HRMS (ESI) calcd. for $C_{17}H_{22}NO_5$ [$(M+H)^+$] 320.1492, found: 320.1489.

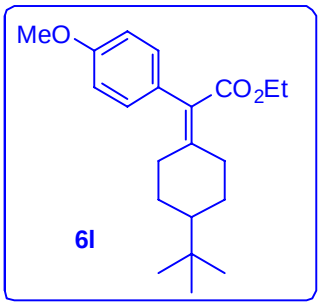
Ethyl 2-(4-Methoxyphenyl)-2-(4-methylcyclohexylidene)acetate (6k)



IR (film) 2952, 2923, 2850, 1731, 1607, 1510, 1457, 1244, 1185, 1034, 835 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.91 (d, J = 6.4 Hz, 3H), 1.22 (t, J = 7.2 Hz, 3H), 1.57-1.74 (m, 6H), 1.80-1.87 (m, 1H), 2.39-2.42 (m, 1H), 2.90-2.94 (m 1H), 3.80 (s, 3H), 4.16 (q, J = 7.2 Hz, 2H), 6.86 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 21.8, 31.4, 32.1, 32.5, 36.3, 36.4, 55.3, 60.6, 113.6, 127.4, 129.9, 130.6, 140.8, 158.7, 169.7; MS (70 eV) *m/z* (%): 288 (100) (M^+), 259(11), 242(89), 213(67), 187(11), 171(39); HRMS (ESI) calcd for $C_{18}H_{24}NaO_3$ [$(M+Na)^+$]

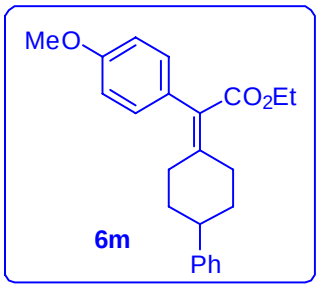
311.1617, found: 311.1616.

Ethyl 2-(4-*tert*-Butylcyclohexylidene)-2-(4-methoxyphenyl)acetate (6l)



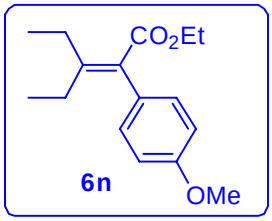
IR (film) 2949, 2968, 2087, 1681, 1366, 1291, 1084, 1058, 747 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.85 (s, 9H), 1.21-1.25 (m, 4H), 1.75-2.03 (m, 6H), 2.46-2.50 (m, 1H), 3.01-3.04 (m, 1H), 2.90-2.94 (m, 1H), 3.80 (s, 3H), 4.16 (q, J = 7.2 Hz, 2H), 6.86 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 27.7, 28.9, 29.0, 31.9, 32.5, 32.6, 41.8, 55.3, 60.6, 113.6, 127.0, 129.9, 130.7, 148.6, 158.6, 169.7; MS (70 eV) *m/z* (%): 330 (100) (M^+), 315(2), 301(5), 284(95), 269(5), 256(21), 241(11), 227(22), 199(89), 185(18), 172(19); HRMS (ESI) calcd for $C_{21}H_{31}O_3$ [$(M+H)^+$] 331.2267, found: 331.2266.

Ethyl 2-(4-Methoxyphenyl)-2-(4-phenylcyclohexylidene)acetate (6m)



IR (film) 2952, 2923, 2850, 1713, 1607, 1510, 1457, 1244, 1185, 1034, 835 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.24 (t, J = 7.2 Hz, 3H), 1.53-1.59 (m, 1H), 1.71-1.75 (m, 1H), 1.93-2.10 (m, 4H), 2.68-2.80 (m, 2H), 3.09-3.12 (m, 1H), 3.81 (s, 3H), 4.18 (q, J = 7.2 Hz, 2H), 6.88 (d, J = 8.4 Hz, 2H), 7.16-7.22 (m, 5H), 7.27-7.31(m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.3, 31.8, 32.5, 35.3, 35.4, 44.4, 55.3, 60.7, 113.7, 126.2, 126.9, 128.5, 128.7, 129.6, 130.6, 146.3, 146.8, 158.8, 169.6; MS (70 eV) *m/z* (%): 350 (100) (M^+), 304(39), 277(22), 194(21), 173(41), 159(22); HRMS (ESI) calcd for $C_{23}H_{26}NaO_3$ [$(M+Na)^+$] 373.1774, found: 373.1779.

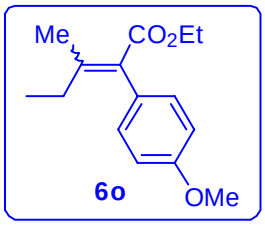
Ethyl 3-Ethyl-2-(4-methoxyphenyl)pent-2-enoate (6n)



IR (film) 2966, 2917, 1712, 1607, 1509, 1244, 1204, 1105, 1032, 836, 808 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.94 (t, J = 7.6 Hz, 3H), 1.13 (t, J = 7.2 Hz, 3H), 1.21 (t, J = 7.2 Hz, 3H), 2.01 (q, J = 7.2 Hz, 2H), 2.40 (q, J = 7.2 Hz, 2H), 3.80 (s, 3H), 4.14 (q, J = 7.2 Hz, 2H), 6.88 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.9, 13.4, 14.3, 25.6, 25.8, 55.3, 60.4, 113.6, 127.8, 129.6, 130.5, 152.9, 158.6, 169.3; MS (70 eV) *m/z* (%):

262 (100) (M^+), 233(16), 216(83), 205(19), 197(83), 187(83), 173(56), 159(83); HRMS (ESI) calcd for $C_{16}H_{23}O_3$ [$(M+H)^+$] 263.1641, found: 263.1637.

Ethyl 2-(4-Methoxyphenyl)-3-methylpent-2-enoate (6o, *E/Z* isomers *E:Z*=1:2.5**)**



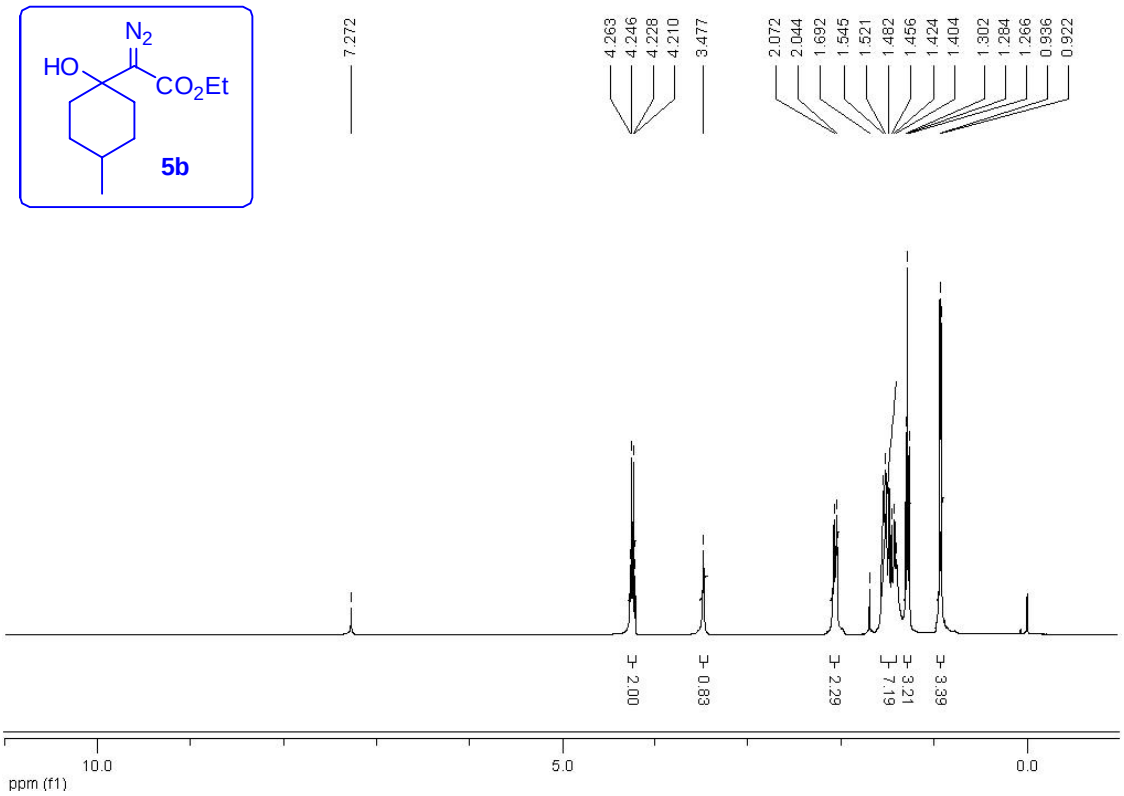
IR (film) 2929, 1711, 1607, 1510, 1245, 1208, 1100, 1031, 836, 733 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.14 (t, J = 7.6 Hz, 3H), 1.22 (t, J = 7.2 Hz, 3H), 1.68 (s, 3H), 2.38 (q, J = 7.2 Hz, 2H), 3.81 (s, 3H), 4.14 (q, J = 7.2 Hz, 2H), 6.88 (d, J = 8.4 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.6, 13.1, 14.3, 19.6, 19.9, 29.1, 29.4, 55.3, 60.51, 60.54, 113.6, 129.7, 130.4, 130.5, 130.6, 147.4, 148.4, 158.6, 169.3; MS (70 eV) *m/z* (%): 248 (100) (M^+), 219(6), 202(62), 191(23), 173(95), 159(72); HRMS (ESI) calcd for $C_{15}H_{21}O_3$ [$(M+H)^+$] 249.1485, found: 249.1481.

References

1 A. Padwa, Y. S. Kulkarni and Z. Zhang, *J. Org. Chem.*, **1990**, *55*, 4144.

2 R. Pellicciari, B. Natalini, B. M. Sadeghpour, M. Marinozzi, J. P. Snyder, B. L. Williamson, J. T. Kuethe and A. Padwa, *J. Am. Chem. Soc*., **1996**, *118*, 1.

3 K. Nagao, M. Chiba, S. -W. Kim, *Synthesis*, **1983**, *3*, 197.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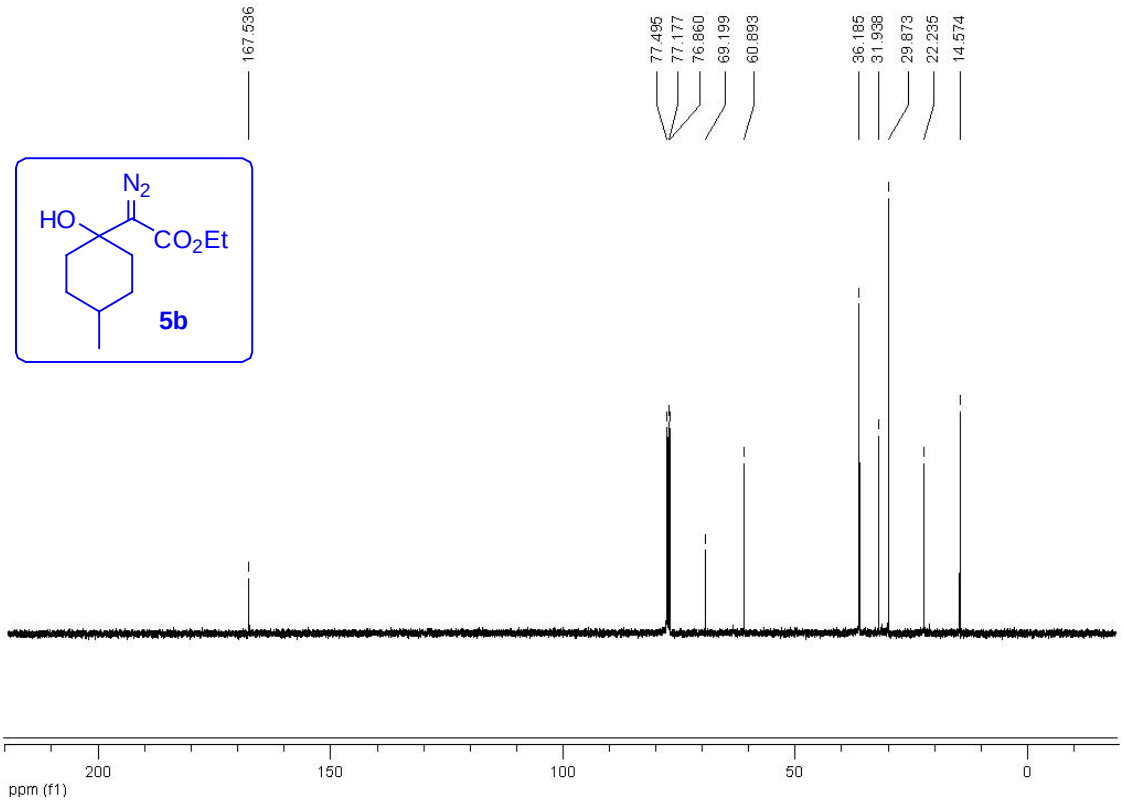
5b
7.272
4.263
4.246
4.228
4.210
3.477
2.072
2.044
1.692
1.545
1.521
1.482
1.456
1.424
1.404
1.302
1.284
1.266
0.936
0.922
2.00
0.83
2.29
7.19
3.21
3.39
10.0
5.0
0.0
ppm (f1)


N2
HO
CO2Et
5b
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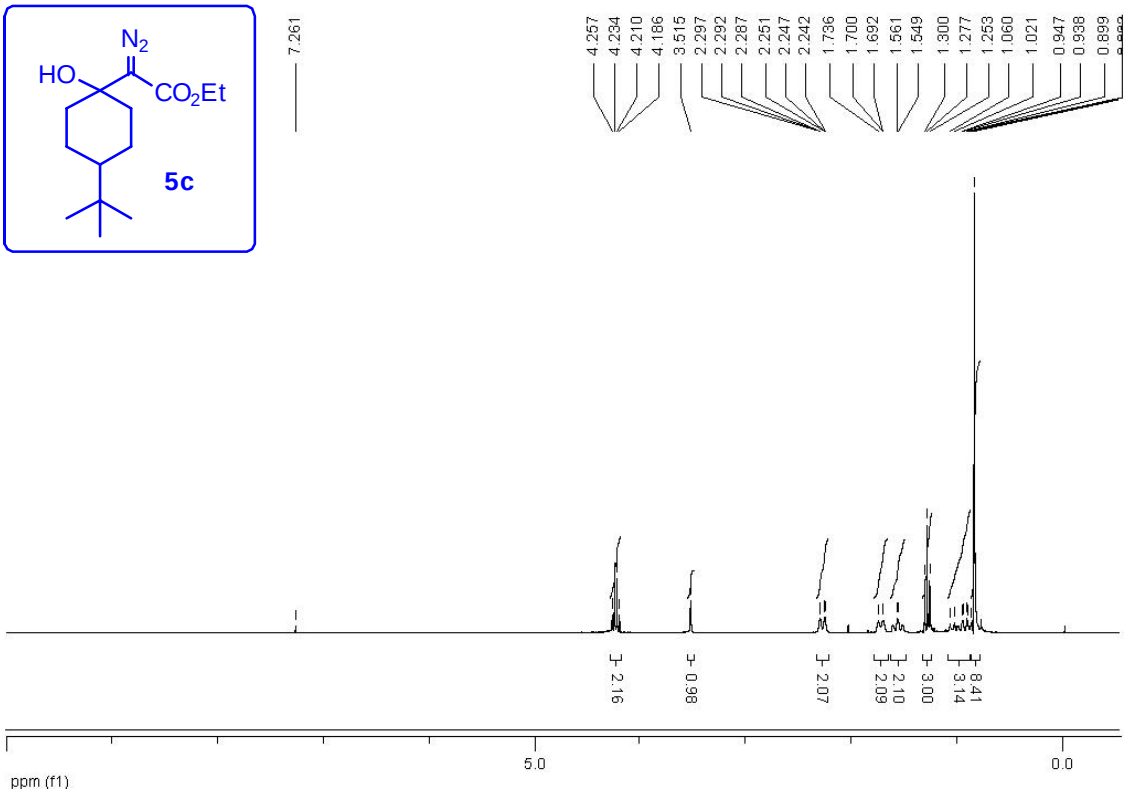
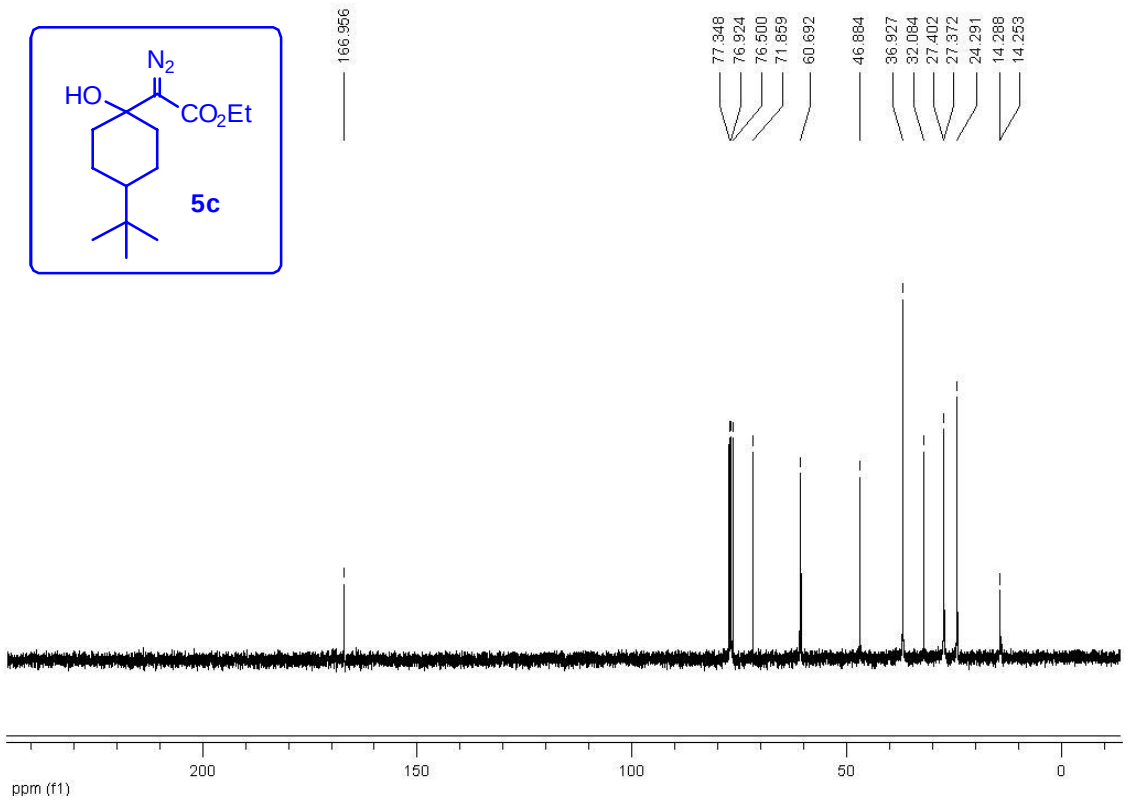
77.495
77.177
76.860
69.199
60.893
36.185
31.938
29.873
22.235
14.574
200
150
100
50
0
ppm (f1)


N2
HO
CO2Et
5c
7.261
4.257
4.234
4.210
4.186
3.515
2.297
2.292
2.287
2.251
2.247
2.242
1.736
1.700
1.692
1.561
1.549
1.300
1.277
1.253
1.060
1.021
0.947
0.938
0.899
2.16
0.98
2.07
2.09
2.10
3.00
3.14
8.41
5.0
0.0
ppm (f1)


N2
HO
CO2Et
5c
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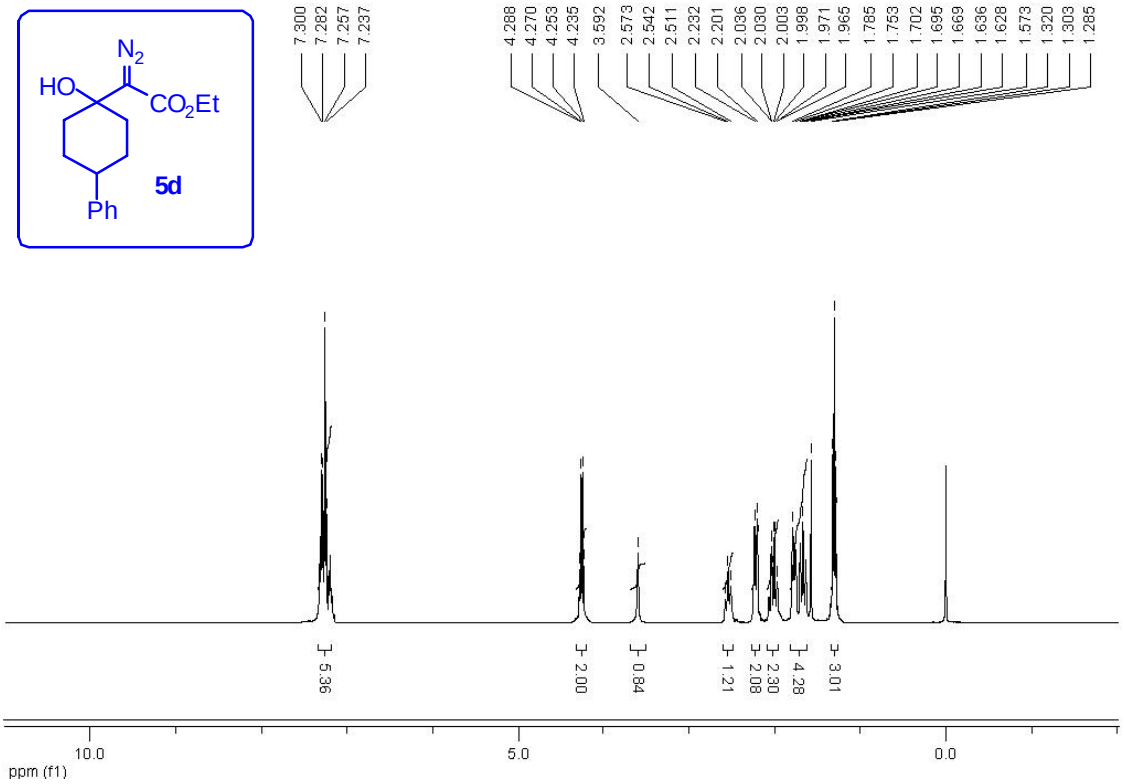
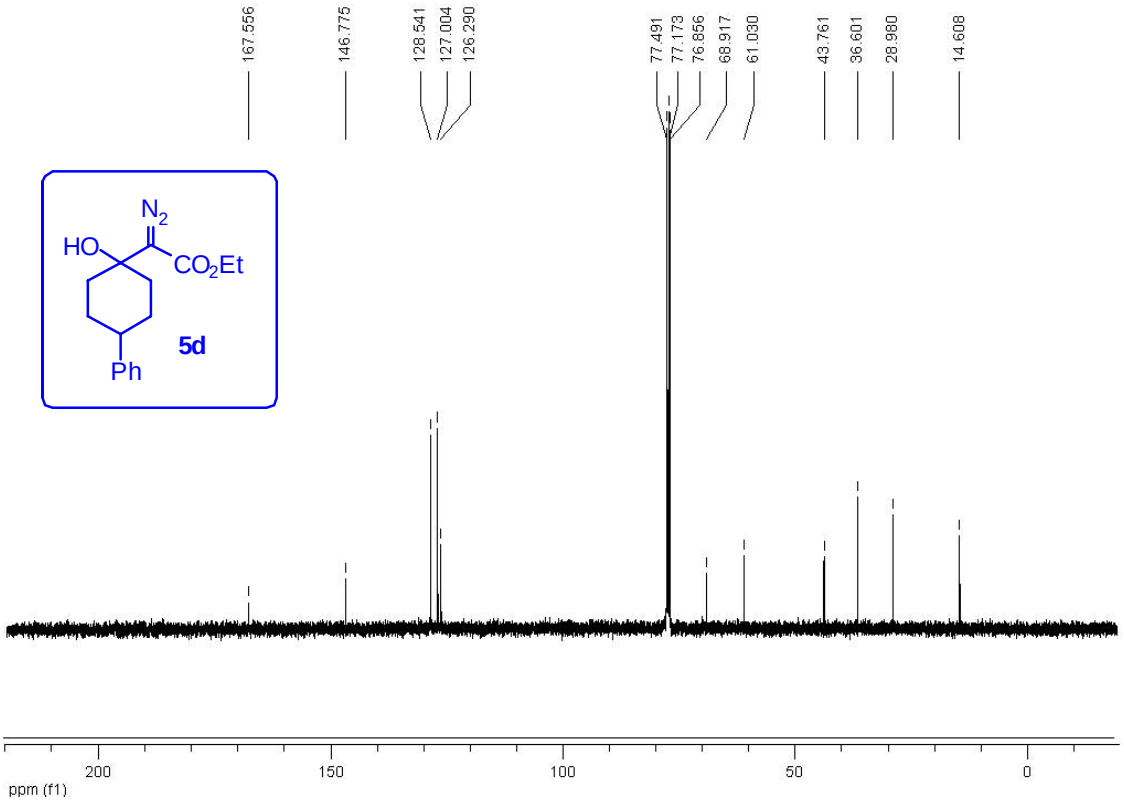
77.348
76.924
76.500
71.859
60.692
46.884
36.927
32.084
27.402
27.372
24.291
14.288
14.253
200
150
100
50
0
ppm (f1)


N2
HO
CO2Et
5d
Ph
7.300
7.282
7.257
7.237
4.288
4.270
4.253
4.235
3.592
2.573
2.542
2.511
2.232
2.201
2.036
2.030
2.003
1.998
1.971
1.965
1.785
1.753
1.702
1.695
1.669
1.636
1.628
1.573
1.320
1.303
1.285
5.36
2.00
0.84
1.21
2.08
2.30
4.28
3.01
10.0
5.0
0.0
ppm (f1)


167.556
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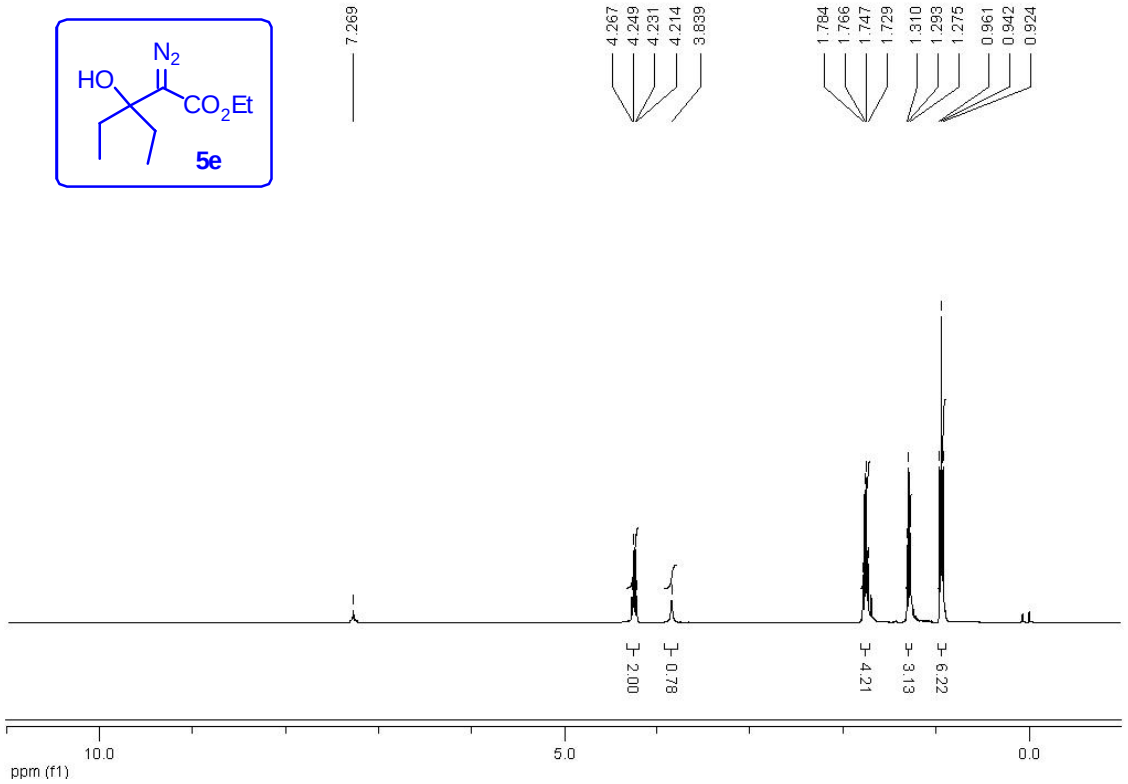
128.541
127.004
126.290
77.491
77.173
76.856
68.917
61.030
43.761
36.601
28.980
14.608
N2
HO
CO2Et
5d
Ph
200
150
100
50
0
ppm (f1)


N2
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CO2Et
5e
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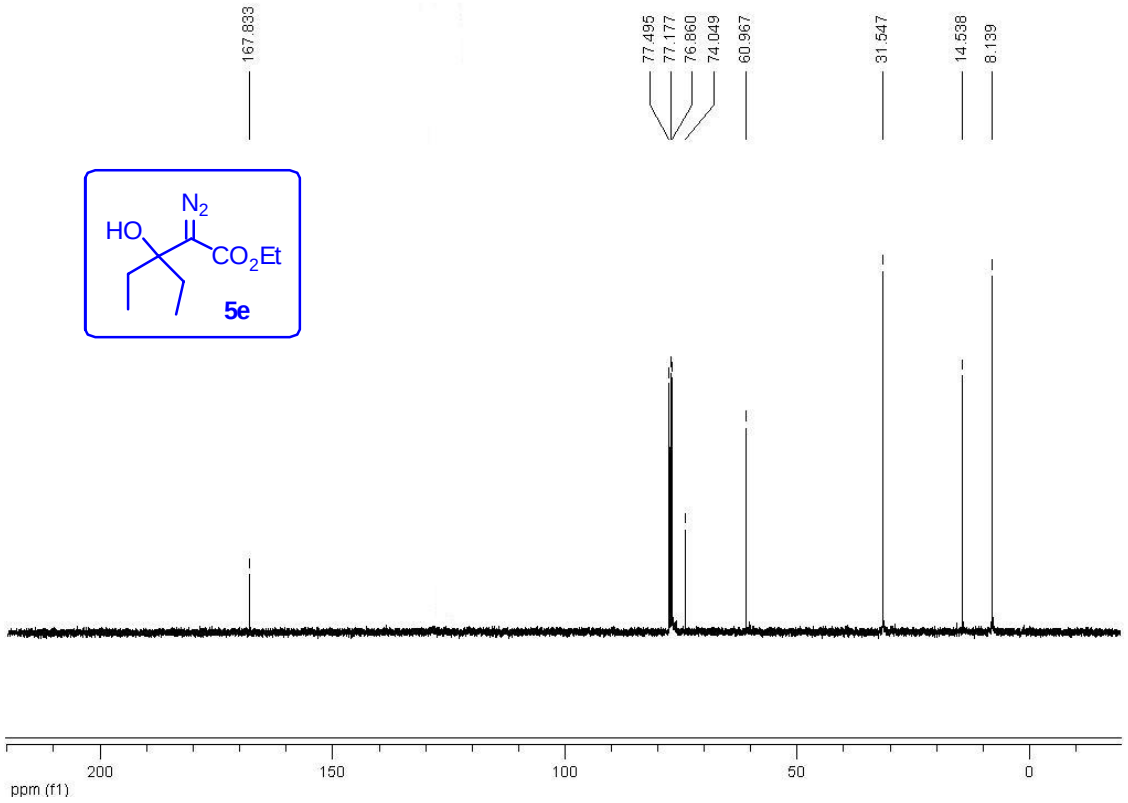
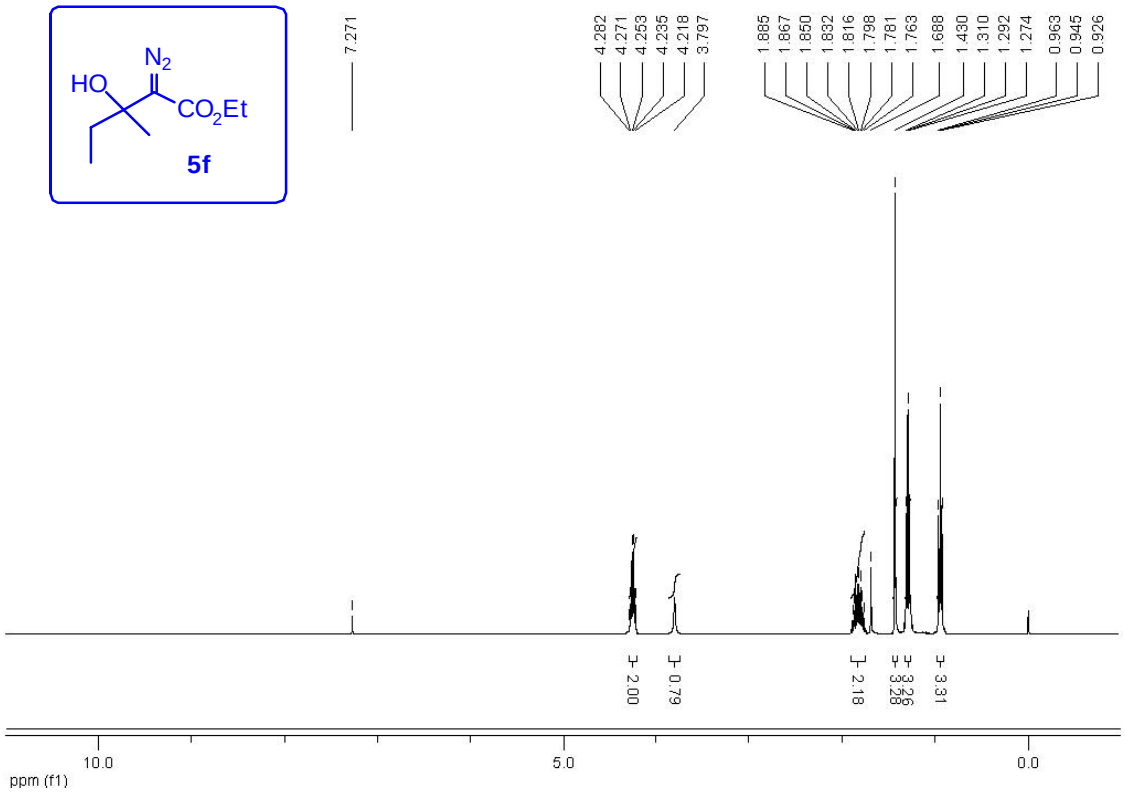
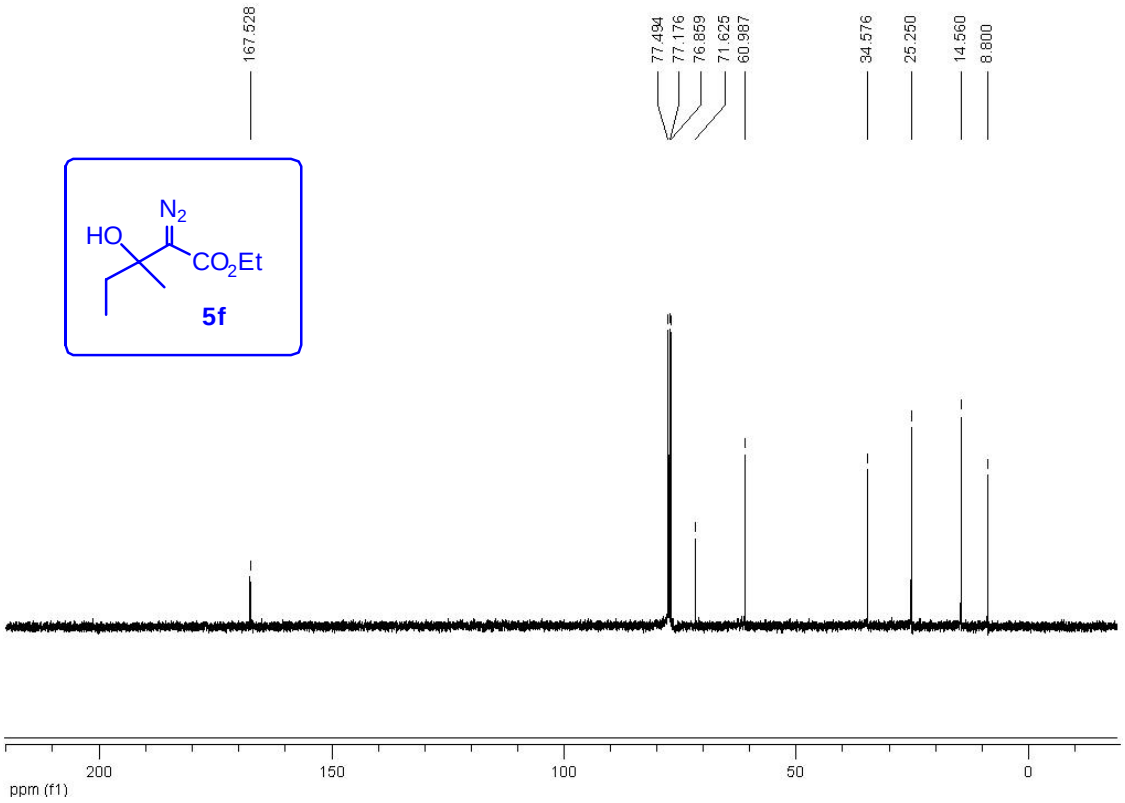
4.267
4.249
4.231
4.214
3.839
1.784
1.766
1.747
1.729
1.310
1.293
1.275
0.961
0.942
0.924
2.00
0.78
4.21
3.13
6.22
10.0
5.0
0.0
ppm (f1)


167.833
77.495
77.177
76.860
74.049
60.967
31.547
14.538
8.139
N2
HO
CO2Et
5e
200
150
100
50
0
ppm (f1)


N2
HO
CO2Et
5f
7.271
4.282
4.271
4.253
4.235
4.218
3.797
1.885
1.867
1.850
1.832
1.816
1.798
1.781
1.763
1.688
1.430
1.310
1.292
1.274
0.963
0.945
0.926
2.00
0.79
2.18
3.26
3.28
3.31
10.0
5.0
0.0
ppm (f1)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77.176
76.859
71.625
60.987
34.576
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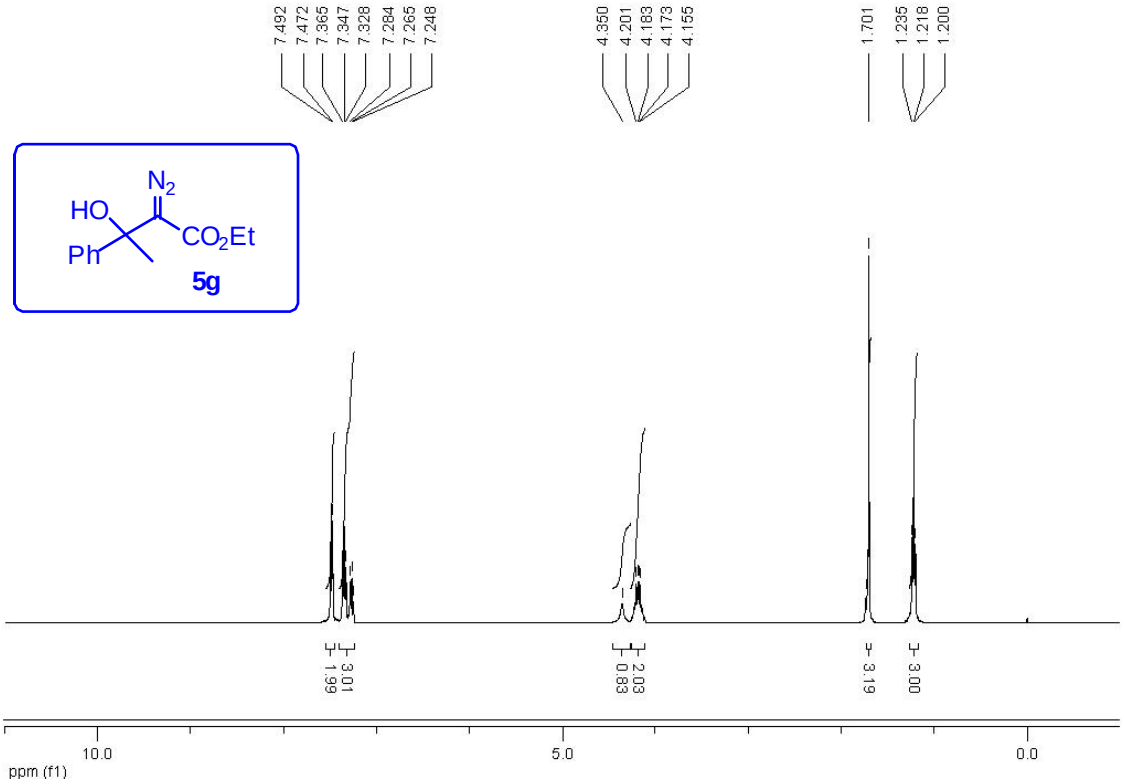
14.560
8.800
N2
HO
CO2Et
5f
200
150
100
50
0
ppm (f1)


7.492
7.472
7.365
7.347
7.328
7.284
7.265
7.248
4.350
4.201
4.183
4.173
4.155
1.701
1.235
1.218
1.200
N2
HO
CO2Et
Ph
5g
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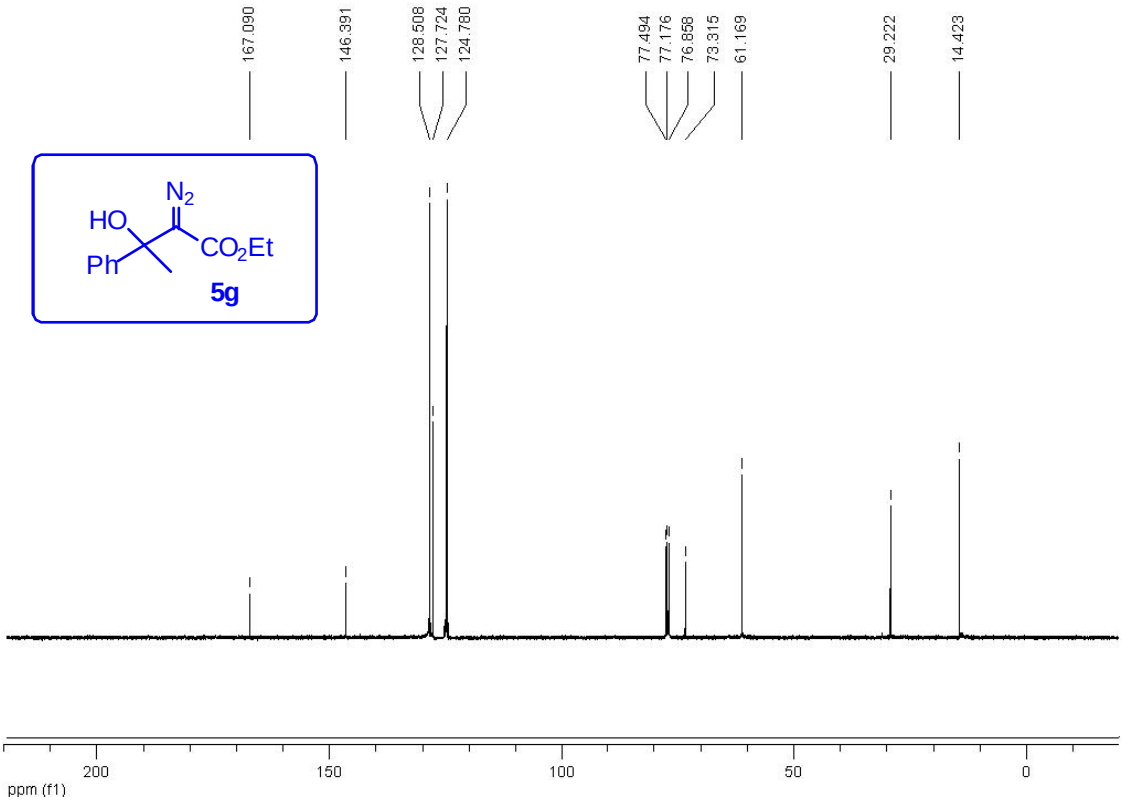
1.01
0.83
2.03
3.19
3.00
10.0
5.0
0.0
ppm (f1)


167.090
146.391
128.508
127.724
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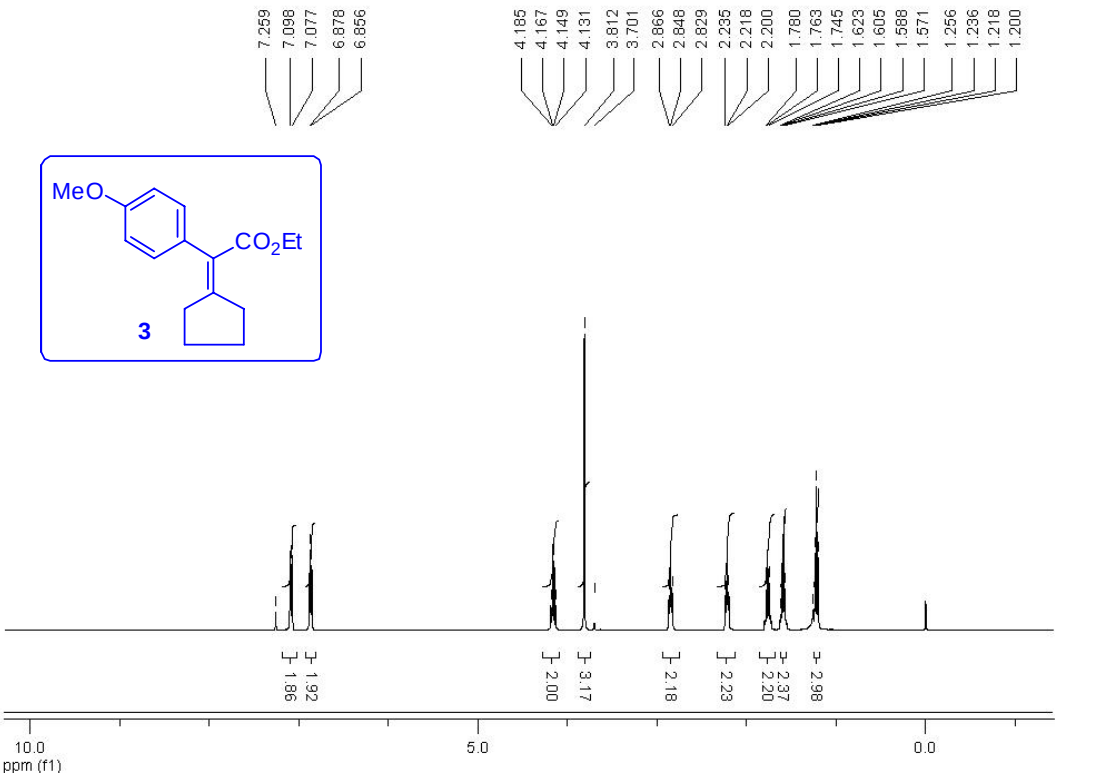
77.176
76.858
73.315
61.169
29.222
14.423
N2
HO
CO2Et
Ph
5g
200
150
100
50
0
ppm (f1)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6.856
4.185
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4.149
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3.701
2.866
2.848
2.829
2.235
2.218
2.200
1.780
1.763
1.745
1.623
1.605
1.588
1.571
1.256
1.236
1.218
1.200
MeO
CO2Et
3
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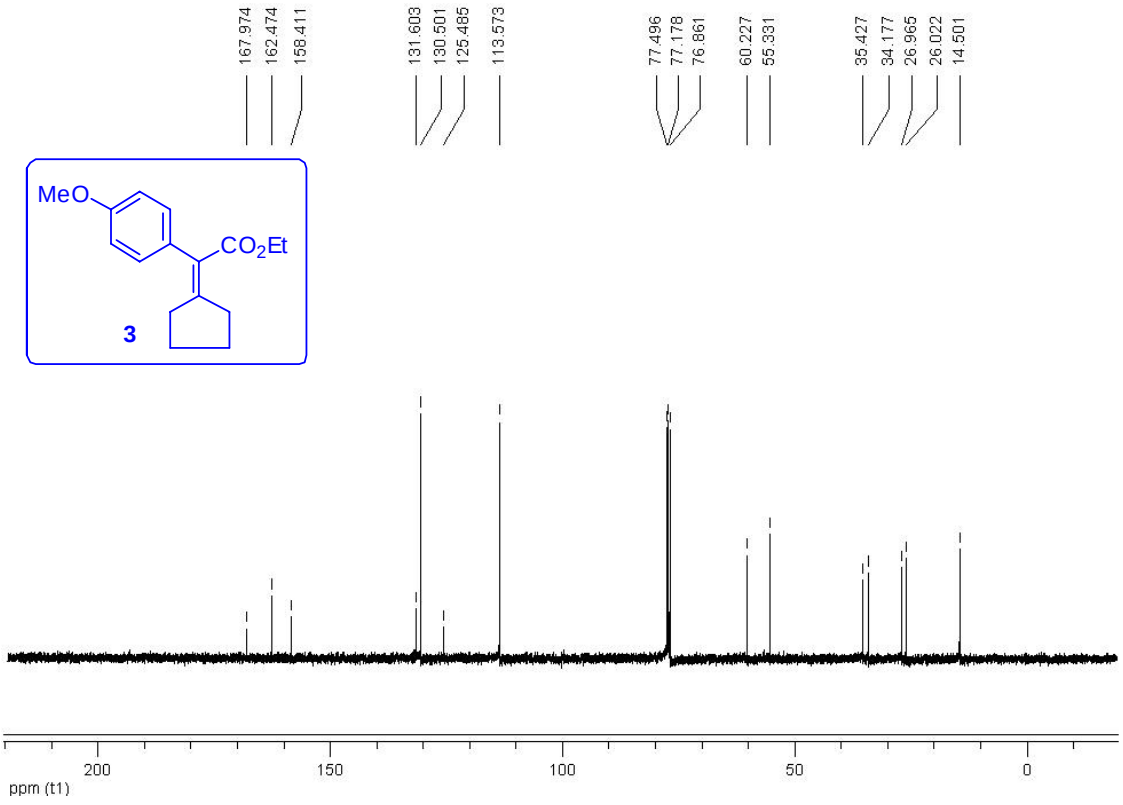
2.23
2.20
2.37
2.68
10.0
5.0
0.0
ppm (f1)


167.974
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130.501
125.485
113.573
77.496
77.178
76.861
60.227
55.331
35.427
34.177
26.965
26.022
14.501
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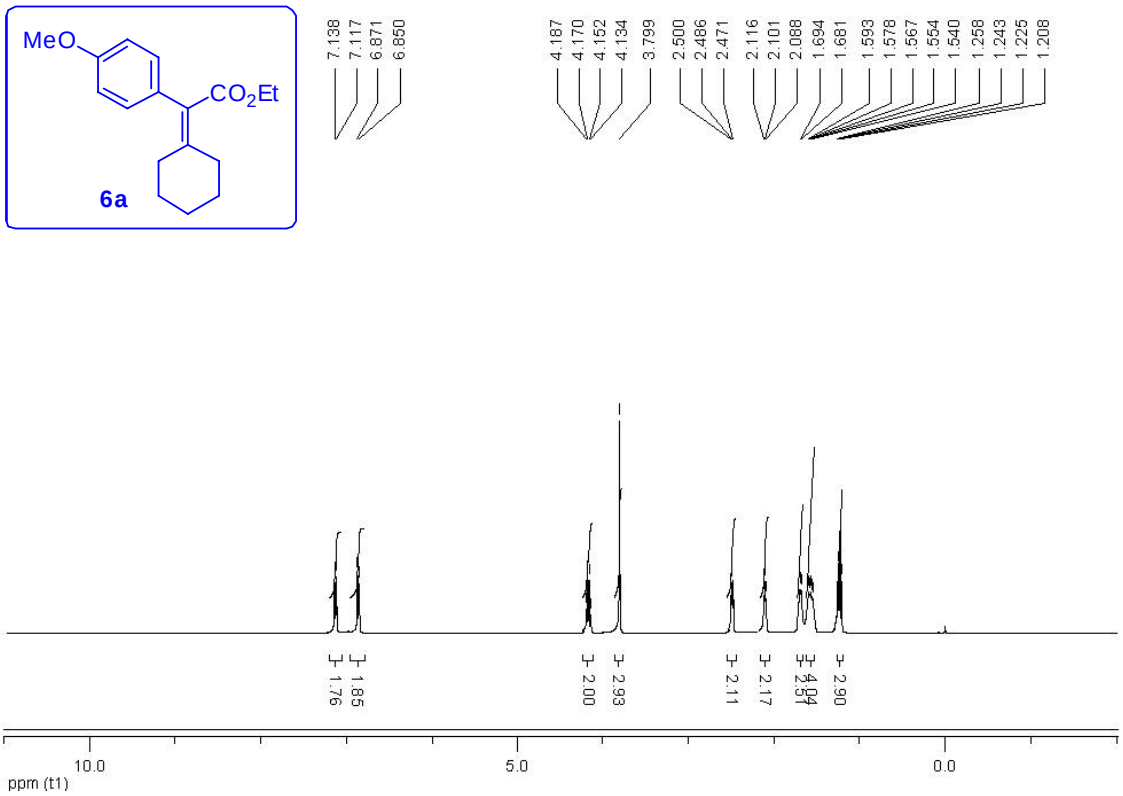
CO2Et
3
200
150
100
50
0
ppm (t1)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4.170
4.152
4.134
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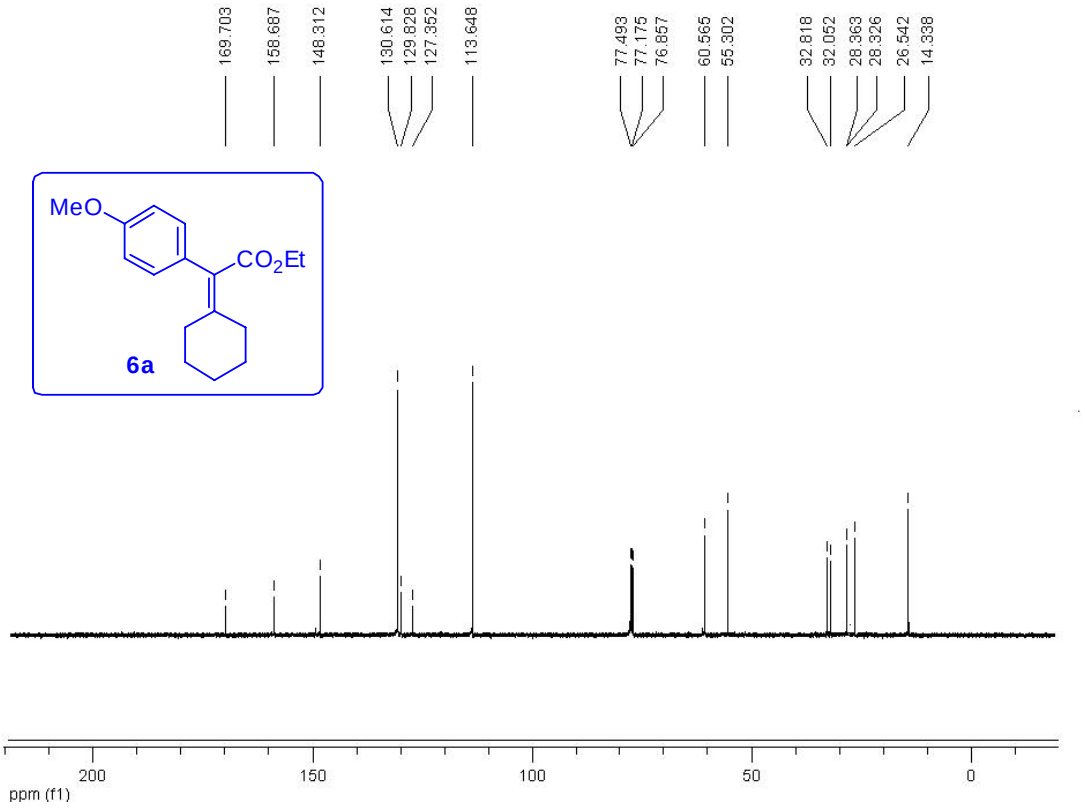
2.500
2.486
2.471
2.116
2.101
2.088
1.694
1.681
1.593
1.578
1.567
1.554
1.540
1.258
1.243
1.225
1.208
1.76
1.85
2.00
2.93
2.11
2.17
4.04
4.51
2.90
10.0
5.0
0.0
ppm (t1)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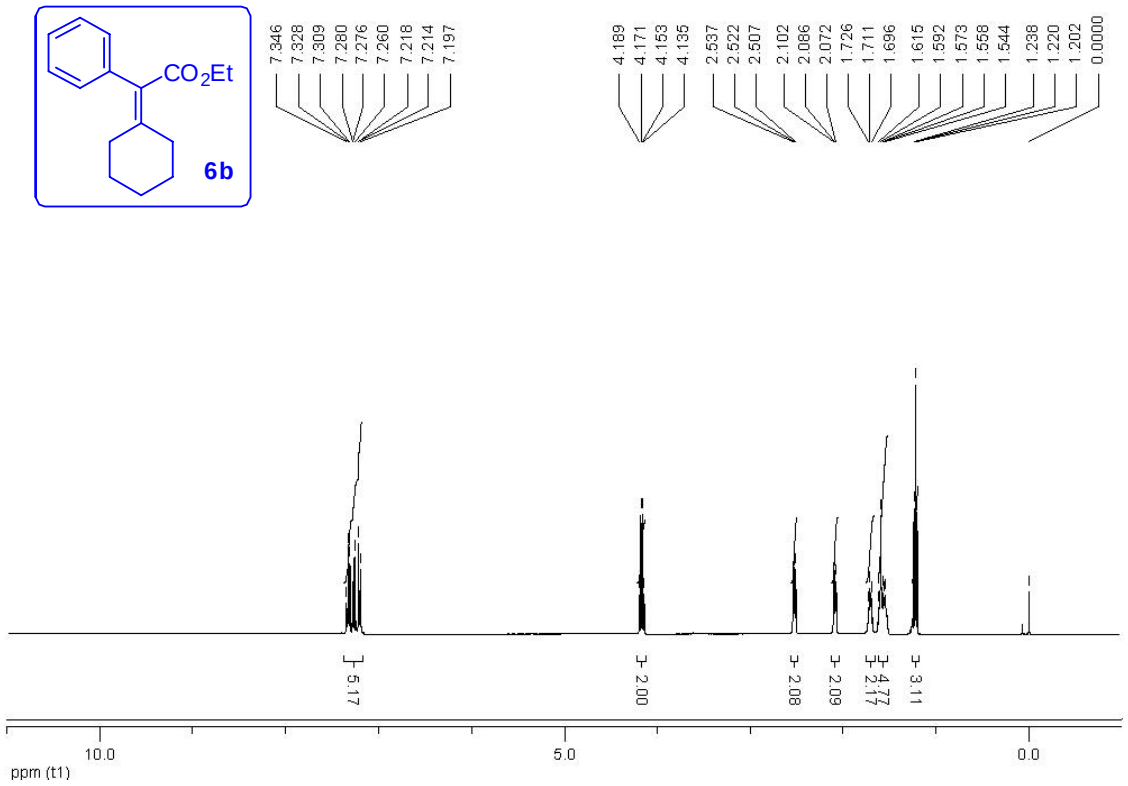
158.687
148.312
130.614
129.828
127.352
113.648
77.493
77.175
76.857
60.565
55.302
32.818
32.052
28.363
28.326
26.542
14.338
MeO
CO2Et
6a
200
150
100
50
0
ppm (f1)


CO2Et
6b
7.346
7.328
7.309
7.280
7.276
7.260
7.218
7.214
7.197
4.189
4.171
4.153
4.135
2.537
2.522
2.507
2.102
2.086
2.072
1.726
1.711
1.696
1.615
1.592
1.573
1.558
1.544
1.238
1.220
1.202
0.0000
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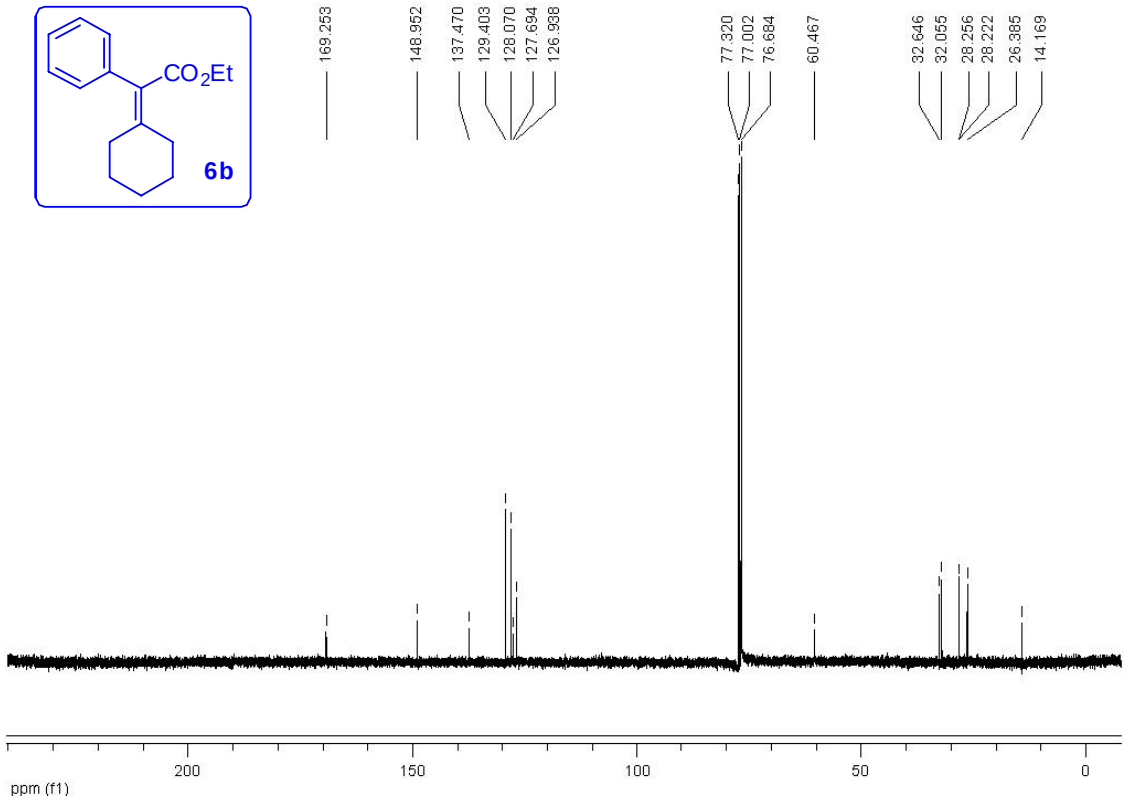
2.00
2.08
2.09
2.17
4.77
3.11
10.0
5.0
0.0
ppm (t1)


CO2Et
6b
169.253
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137.470
129.403
128.070
127.694
126.938
77.320
77.002
76.684
60.467
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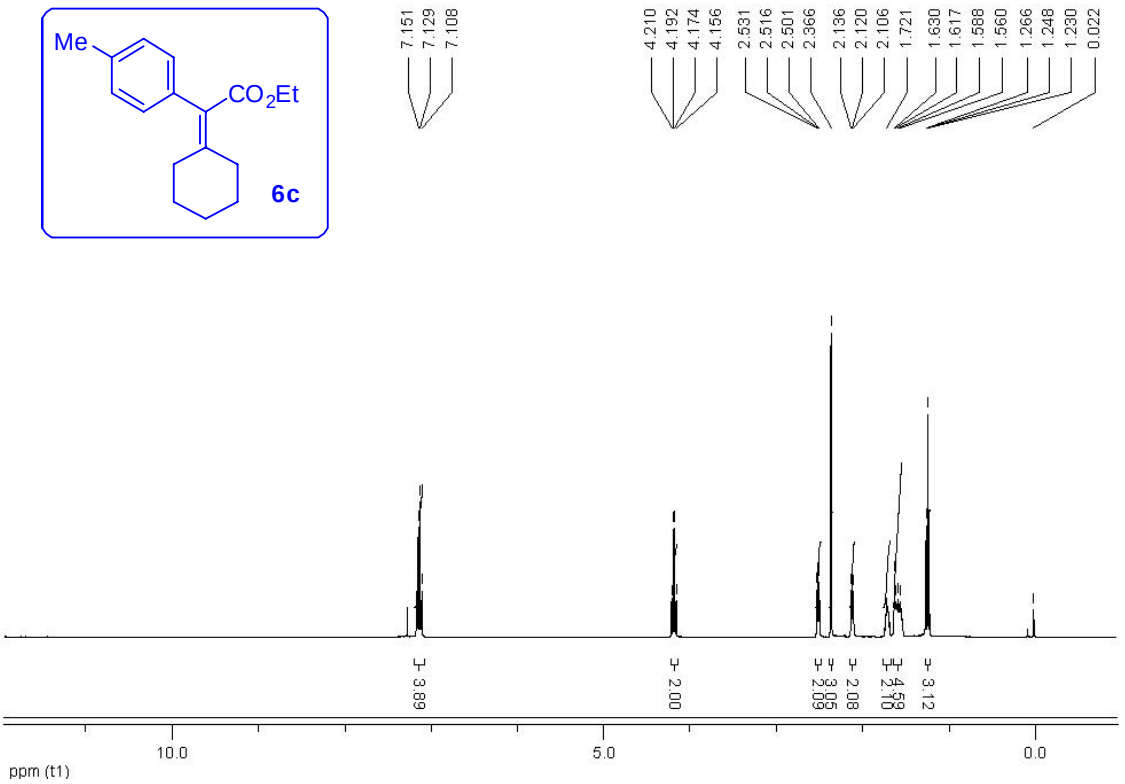
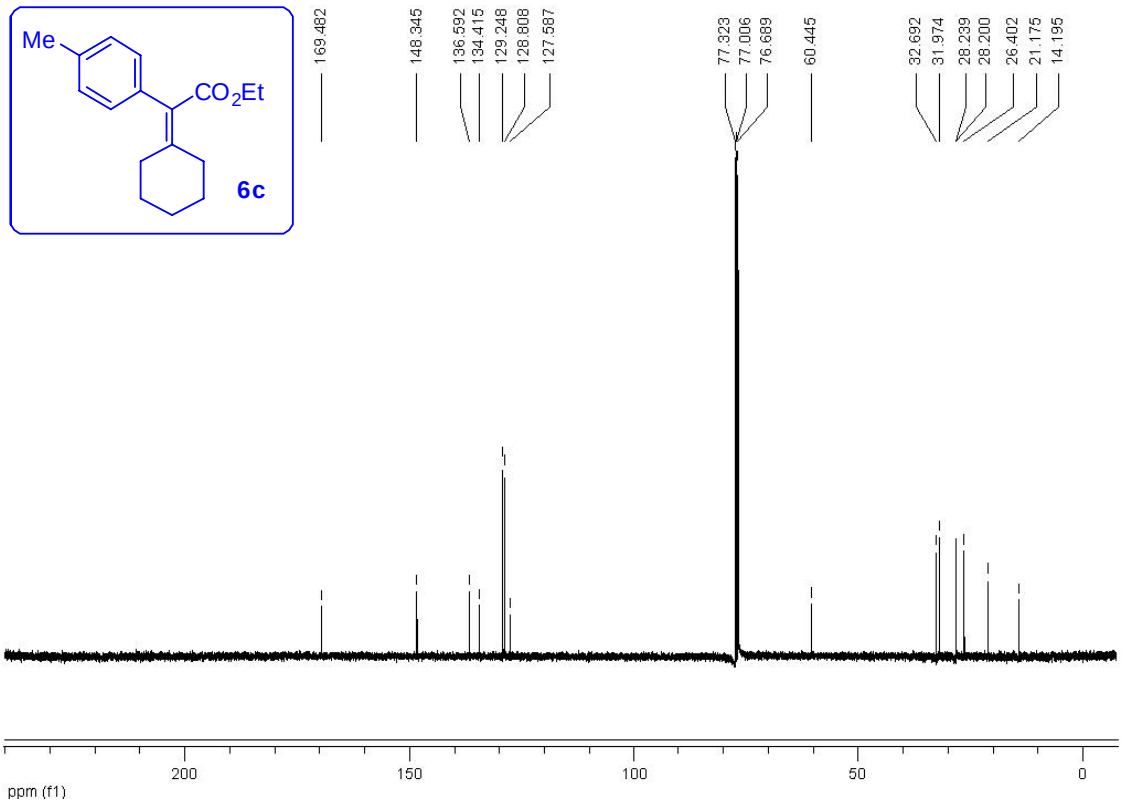
32.055
28.256
28.222
26.385
14.169
200
150
100
50
0
ppm (f1)


Me
CO2Et
6c
7.151
7.129
7.108
4.210
4.192
4.174
4.156
2.531
2.516
2.501
2.366
2.136
2.120
2.106
1.721
1.630
1.617
1.588
1.560
1.266
1.248
1.230
0.022
3.89
2.00
3.05
2.08
4.58
2.10
3.12
10.0
5.0
0.0
ppm (t1)


Me
CO2Et
6c
169.482
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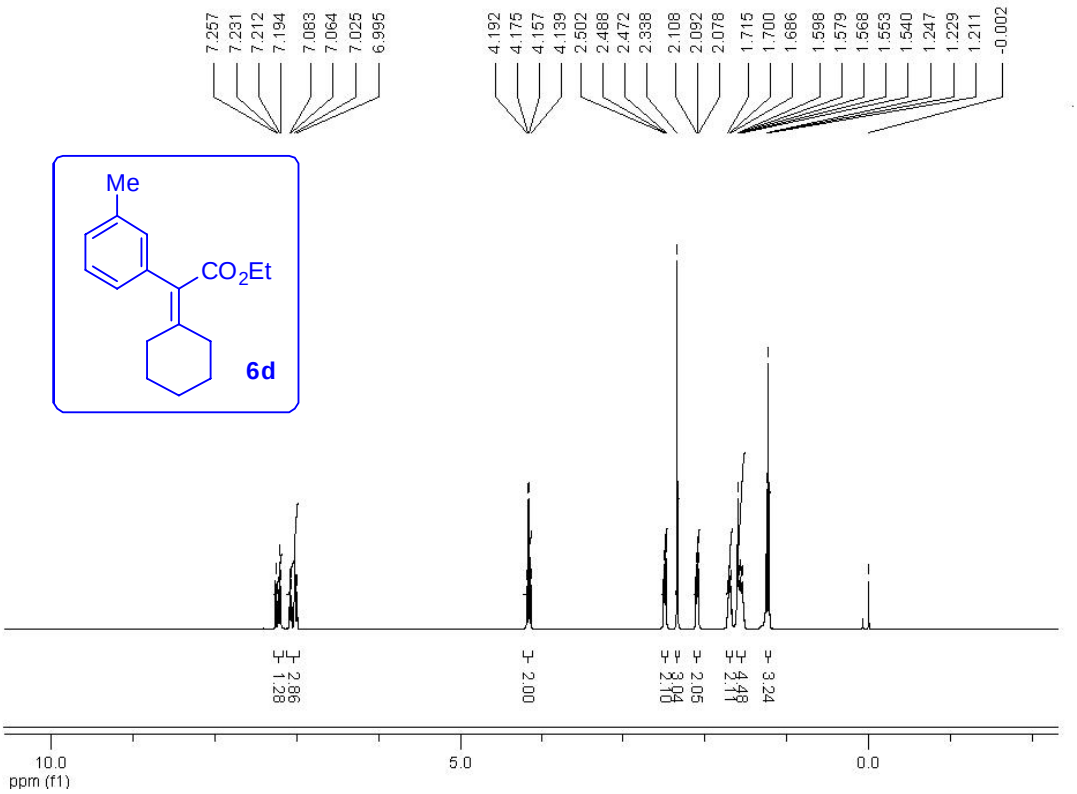
136.592
134.415
129.248
128.808
127.587
77.323
77.006
76.689
60.445
32.692
31.974
28.239
28.200
26.402
21.175
14.195
200
150
100
50
0
ppm (f1)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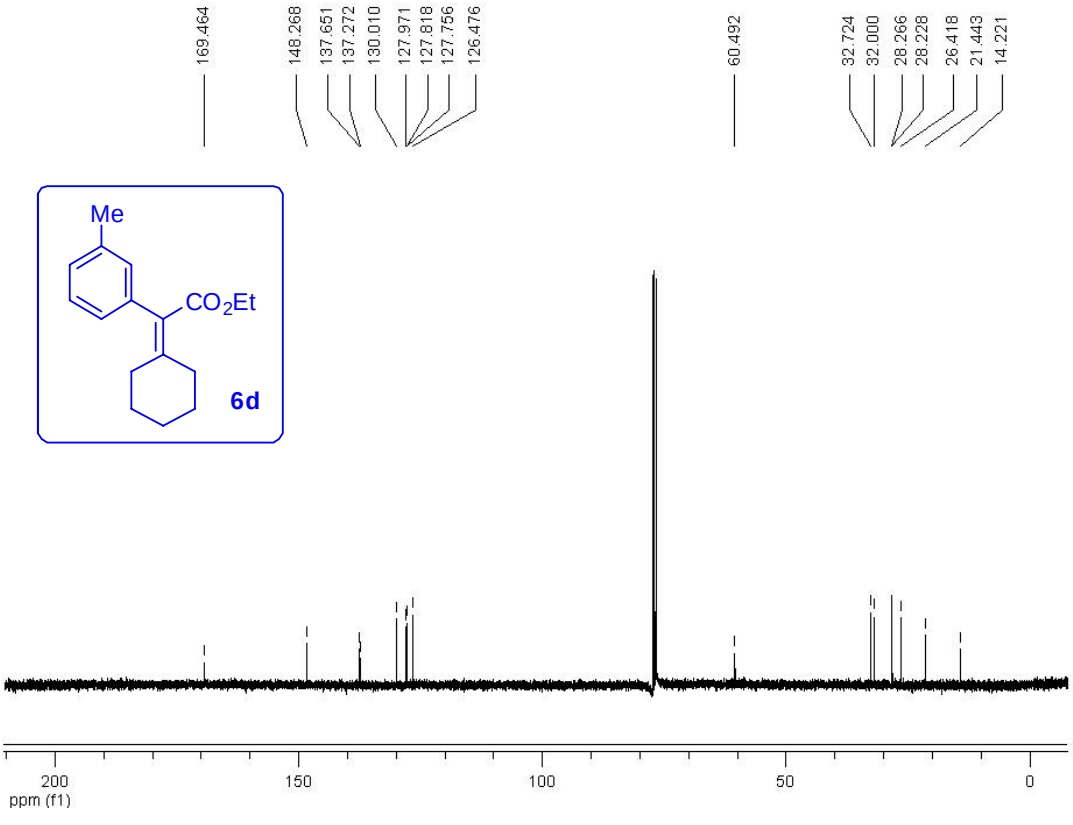
7.231
7.212
7.194
7.083
7.064
7.025
6.995
4.192
4.175
4.157
4.139
2.502
2.488
2.472
2.338
2.108
2.092
2.078
1.715
1.700
1.686
1.598
1.579
1.568
1.553
1.540
1.247
1.229
1.211
-0.002
Me
CO2Et
6d
1.28
2.86
2.00
3.04
2.10
2.05
4.48
2.11
3.24
10.0
5.0
0.0
ppm (f1)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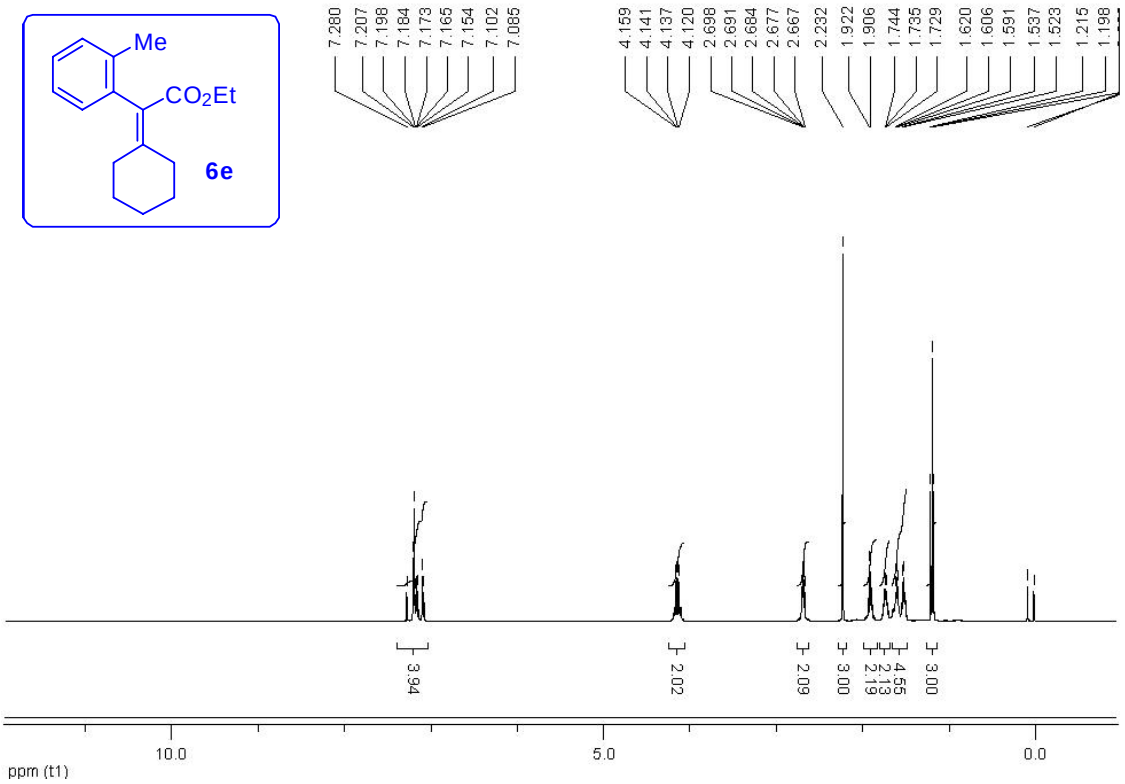
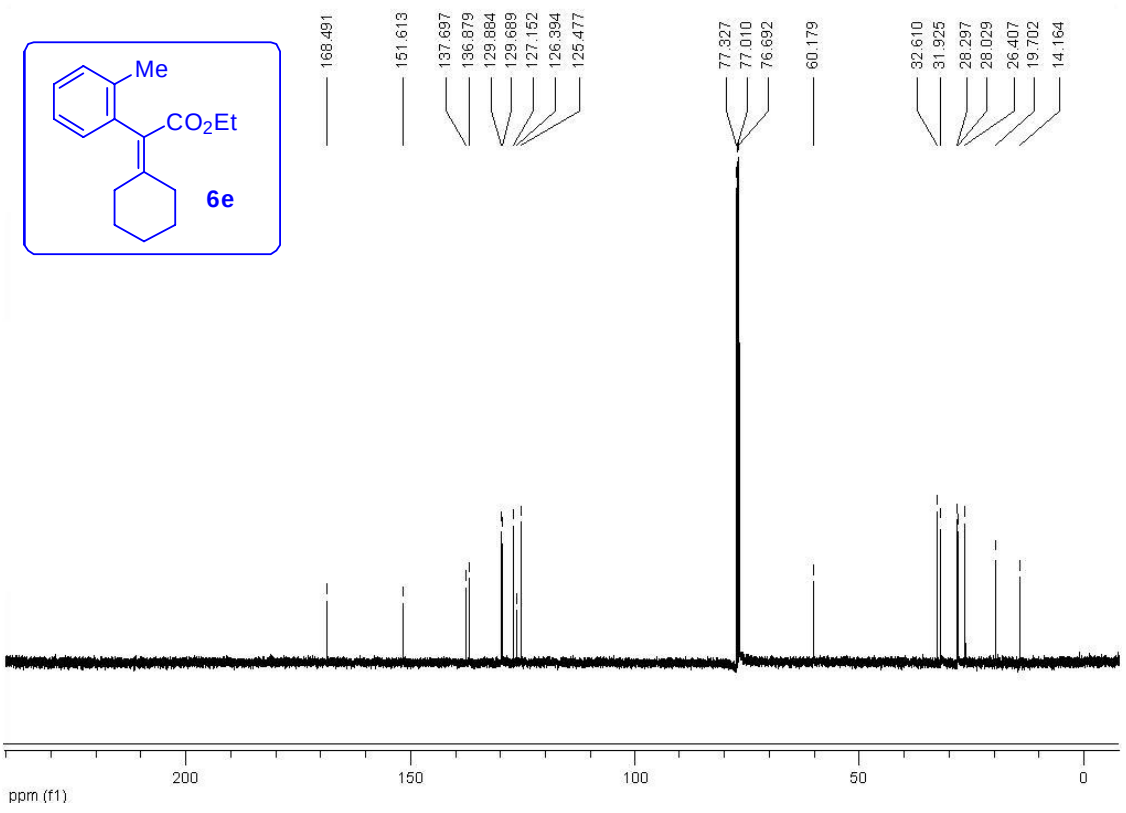
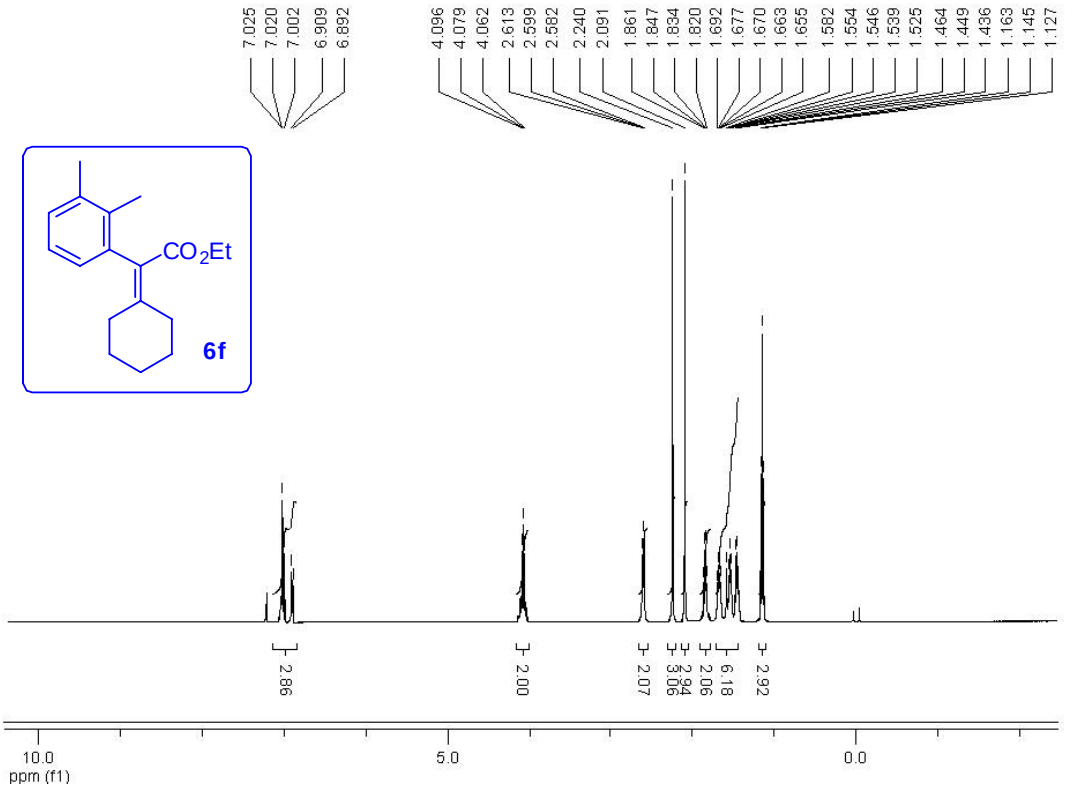
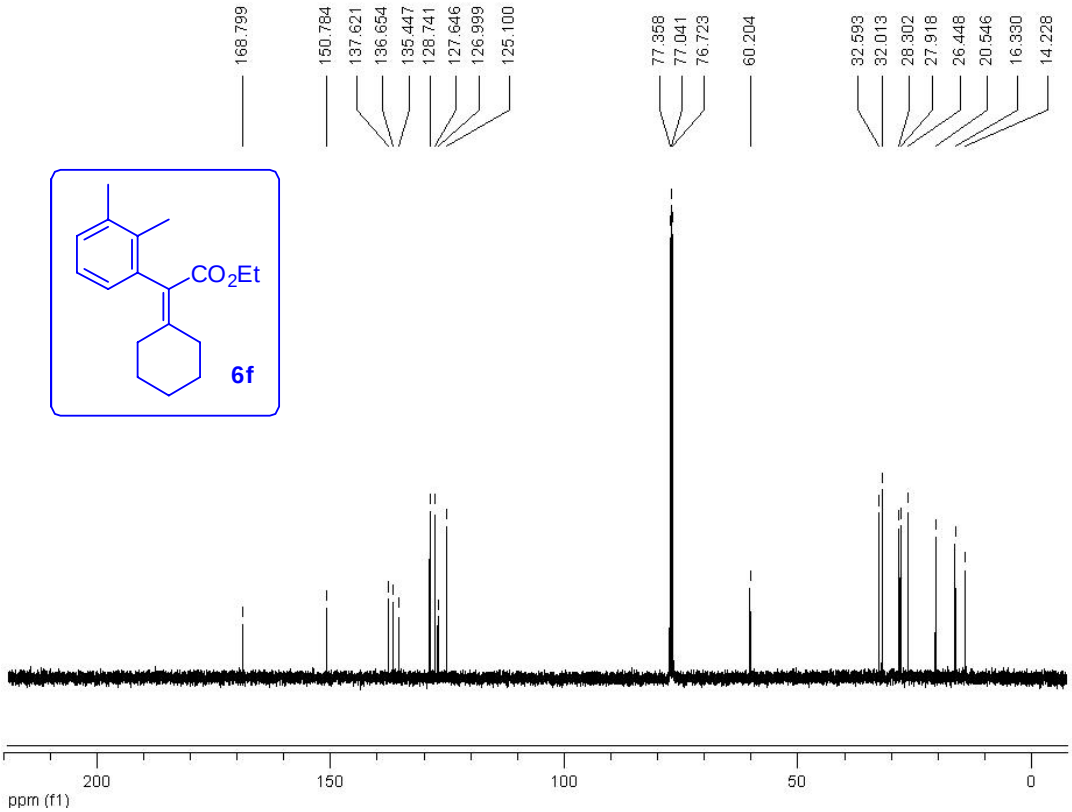
137.651
137.272
130.010
127.971
127.818
127.756
126.476
60.492
32.724
32.000
28.266
28.228
26.418
21.443
14.221
Me
CO2Et
6d
200
150
100
50
0
ppm (f1)


Me
CO2Et
6e
7.280
7.207
7.198
7.184
7.173
7.165
7.154
7.102
7.085
4.159
4.141
4.137
4.120
2.698
2.691
2.684
2.677
2.667
2.232
1.922
1.906
1.744
1.735
1.729
1.620
1.606
1.591
1.537
1.523
1.215
1.198
3.94
2.02
2.09
3.00
2.13
4.55
3.00
10.0
5.0
0.0
ppm (t1)


Me
CO2Et
6e
168.491
151.613
137.697
136.879
129.884
129.689
127.152
126.394
125.477
77.327
77.010
76.692
60.179
32.610
31.925
28.297
28.029
26.407
19.702
14.164
200
150
100
50
0
ppm (f1)


7.025
7.020
7.002
6.909
6.892
4.096
4.079
4.062
2.613
2.599
2.582
2.240
2.091
1.861
1.847
1.834
1.820
1.692
1.677
1.670
1.663
1.655
1.582
1.554
1.546
1.539
1.525
1.464
1.449
1.436
1.163
1.145
1.127
CO2Et
6f
2.86
2.00
2.07
3.06
2.84
2.06
1.18
2.92
10.0
5.0
0.0
ppm (f1)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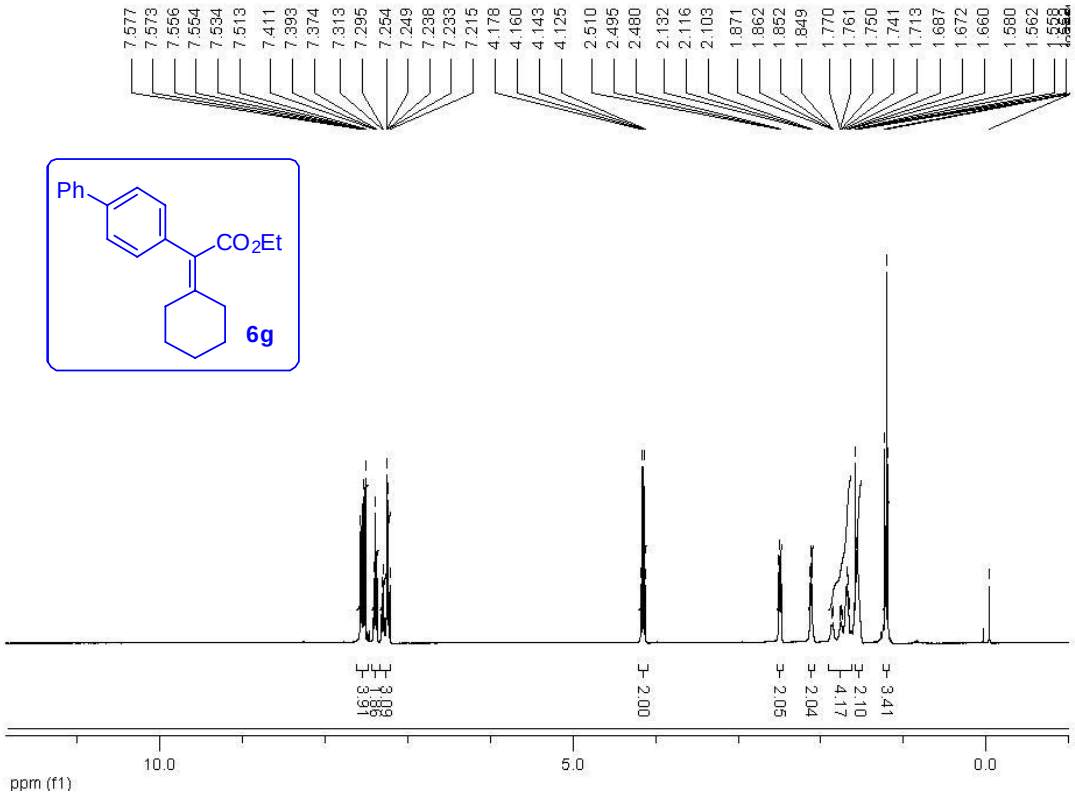
137.621
136.654
135.447
128.741
127.646
126.999
125.100
77.358
77.041
76.723
60.204
32.593
32.013
28.302
27.918
26.448
20.546
16.330
14.228
CO2Et
6f
200
150
100
50
0
ppm (f1)


7.577
7.573
7.556
7.554
7.534
7.513
7.411
7.393
7.374
7.313
7.295
7.254
7.249
7.238
7.233
7.215
4.178
4.160
4.143
4.125
2.510
2.495
2.480
2.132
2.116
2.103
1.871
1.862
1.852
1.849
1.770
1.761
1.750
1.741
1.713
1.687
1.672
1.660
1.580
1.562
Ph
CO2Et
6g
3.91
3.98
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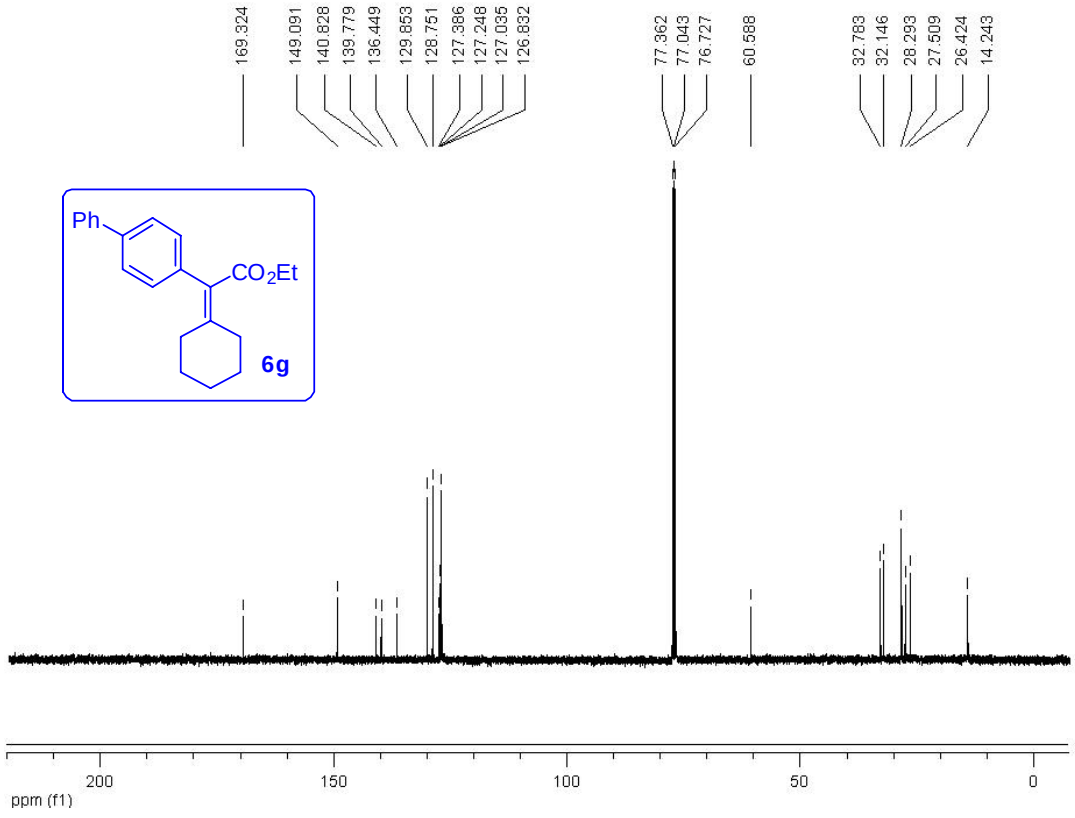
2.05
2.04
4.17
2.10
3.41
10.0
5.0
0.0
ppm (f1)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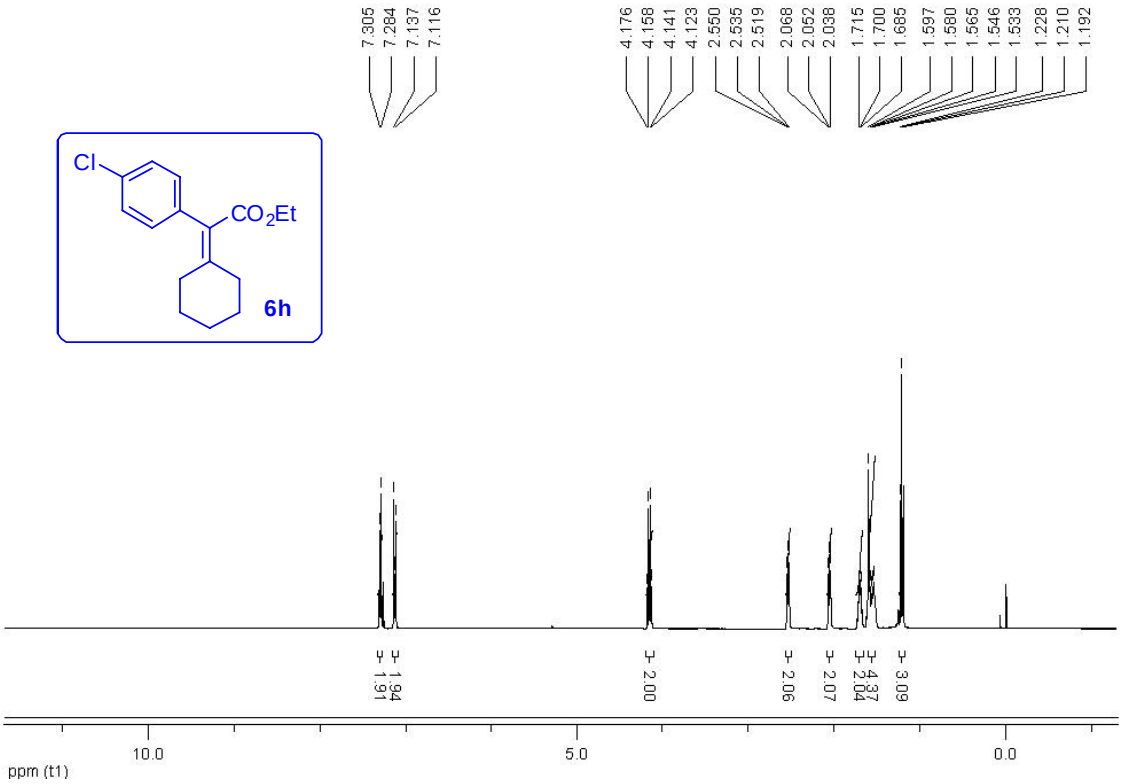
127.386
127.248
127.035
126.832
77.362
77.043
76.727
60.588
32.783
32.146
28.293
27.509
26.424
14.243
Ph
CO2Et
6g
200
150
100
50
0
ppm (f1)


7.305
7.284
7.137
7.116
4.176
4.158
4.141
4.123
2.550
2.535
2.519
2.068
2.052
2.038
1.715
1.700
1.685
1.597
1.580
1.565
1.546
1.533
1.228
1.210
1.192
Cl
CO2Et
6h
1.91
1.94
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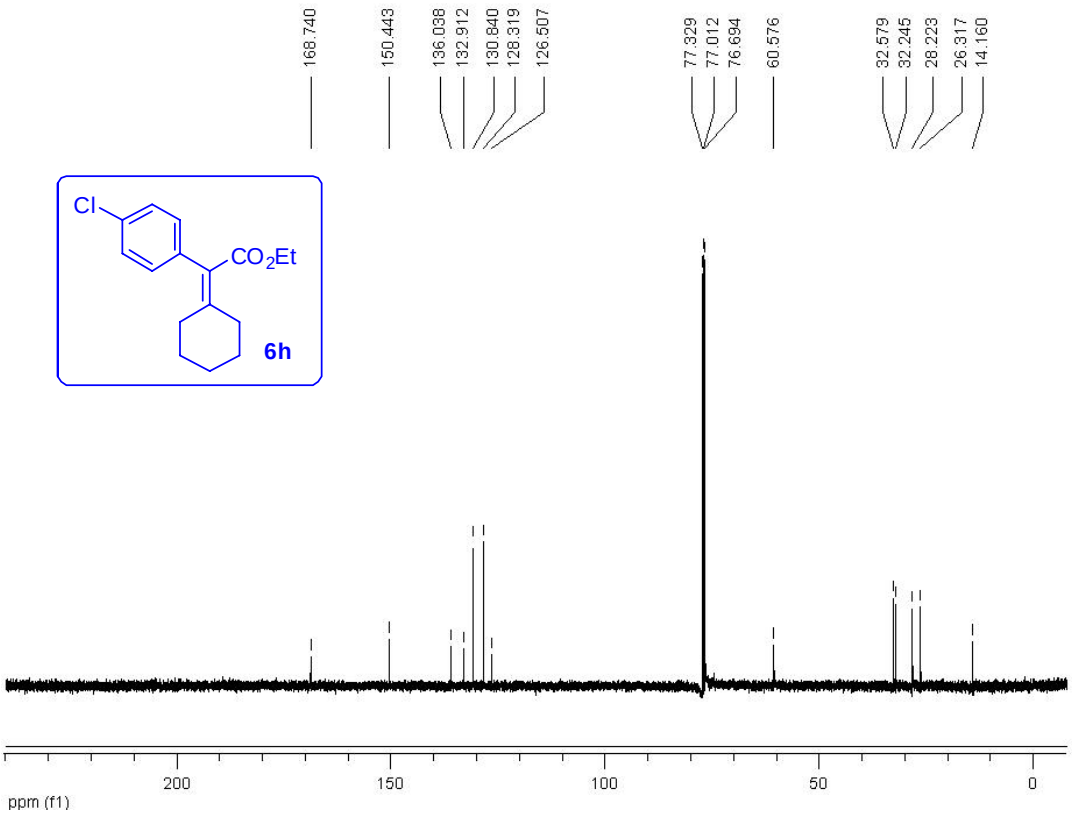
2.06
2.07
2.74
2.87
3.09
10.0
5.0
0.0
ppm (t1)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150.443
136.038
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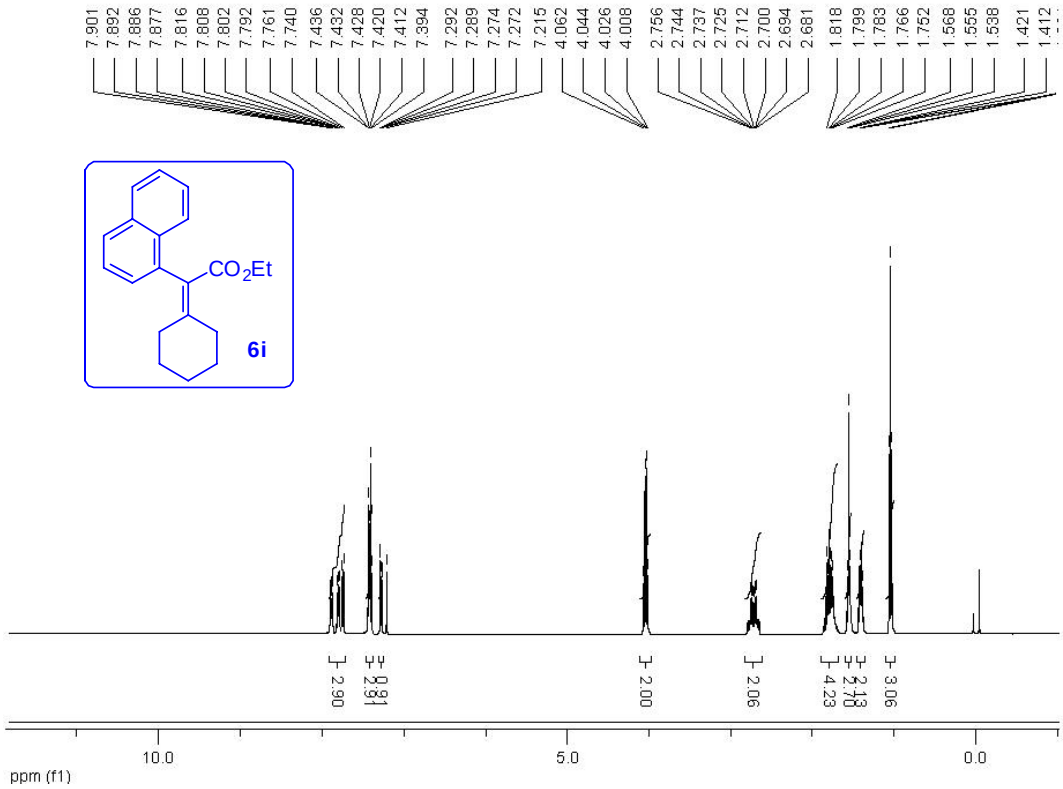
130.840
128.319
126.507
77.329
77.012
76.694
60.576
32.579
32.245
28.223
26.317
14.160
Cl
CO2Et
6h
200
150
100
50
0
ppm (f1)


7.901
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7.816
7.808
7.802
7.792
7.761
7.740
7.436
7.432
7.428
7.420
7.412
7.394
7.292
7.289
7.274
7.272
7.215
4.062
4.044
4.026
4.008
2.756
2.744
2.737
2.725
2.712
2.700
2.694
2.681
1.818
1.799
1.783
1.766
1.752
1.568
1.555
1.538
1.421
1.412
CO2Et
6i
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2.00
2.06
4.23
2.18
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5.0
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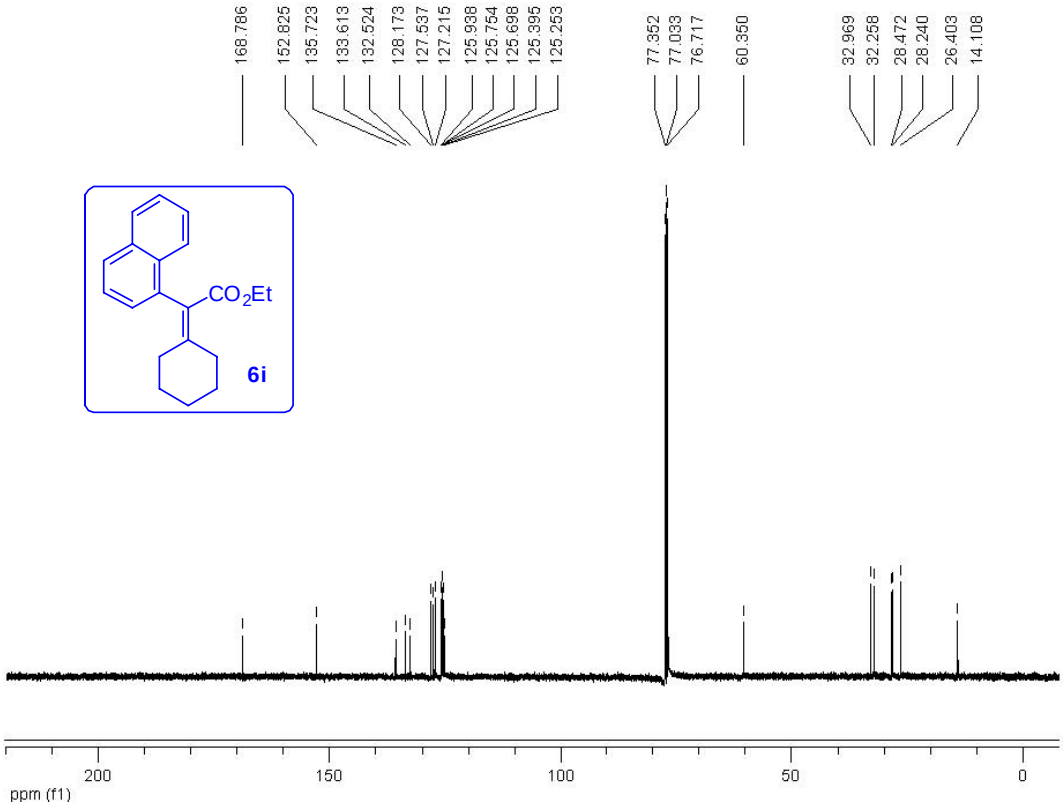
ppm (f1)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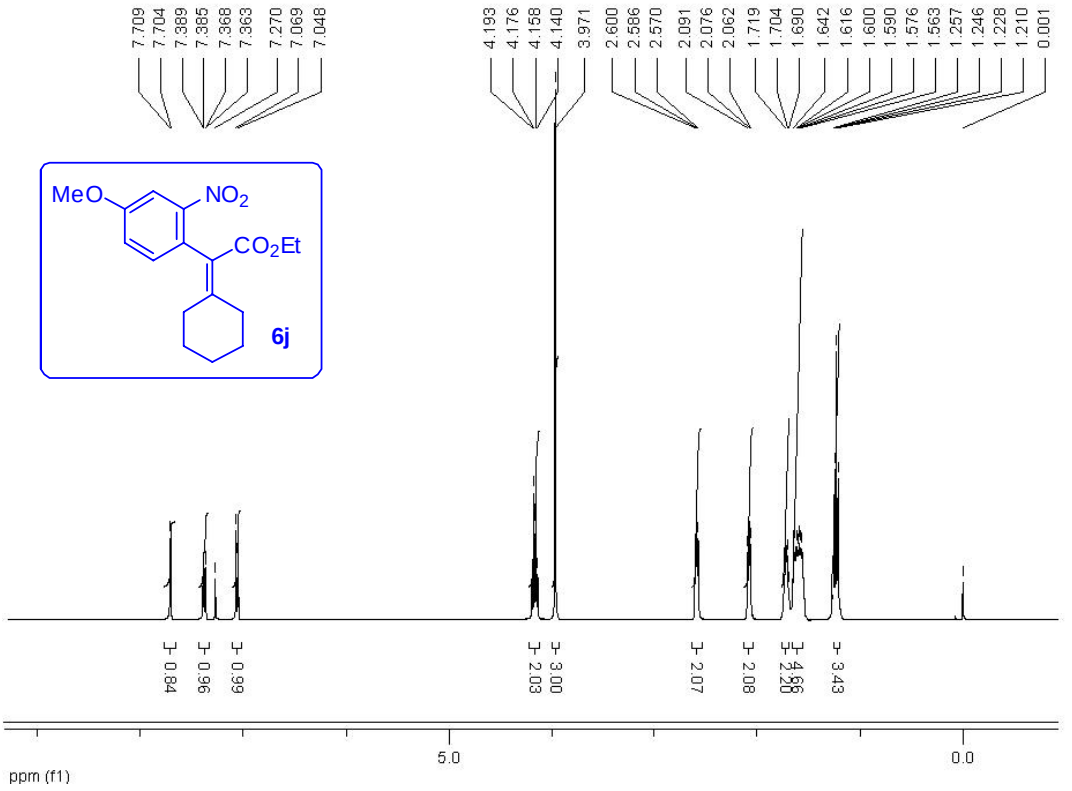
135.723
133.613
132.524
128.173
127.537
127.215
125.938
125.754
125.698
125.395
125.253
77.352
77.033
76.717
60.350
32.969
32.258
28.472
28.240
26.403
14.108
CO2Et
6i
200
150
100
50
0
ppm (f1)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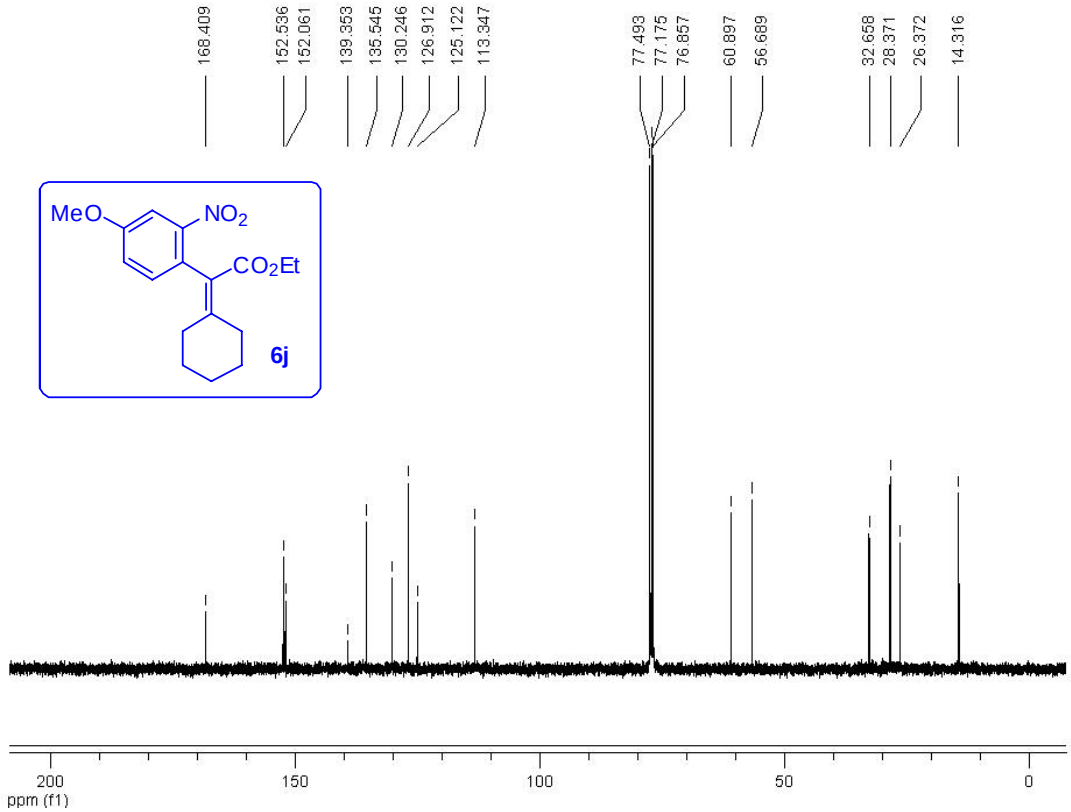
7.704
7.389
7.385
7.368
7.363
7.270
7.069
7.048
4.193
4.176
4.158
4.140
3.971
2.600
2.586
2.570
2.091
2.076
2.062
1.719
1.704
1.690
1.642
1.616
1.600
1.590
1.576
1.563
1.257
1.246
1.228
1.210
0.001
MeO
NO2
CO2Et
6j
0.84
0.96
0.99
2.03
3.00
2.07
2.08
4.96
4.20
3.43
5.0
0.0
ppm (f1)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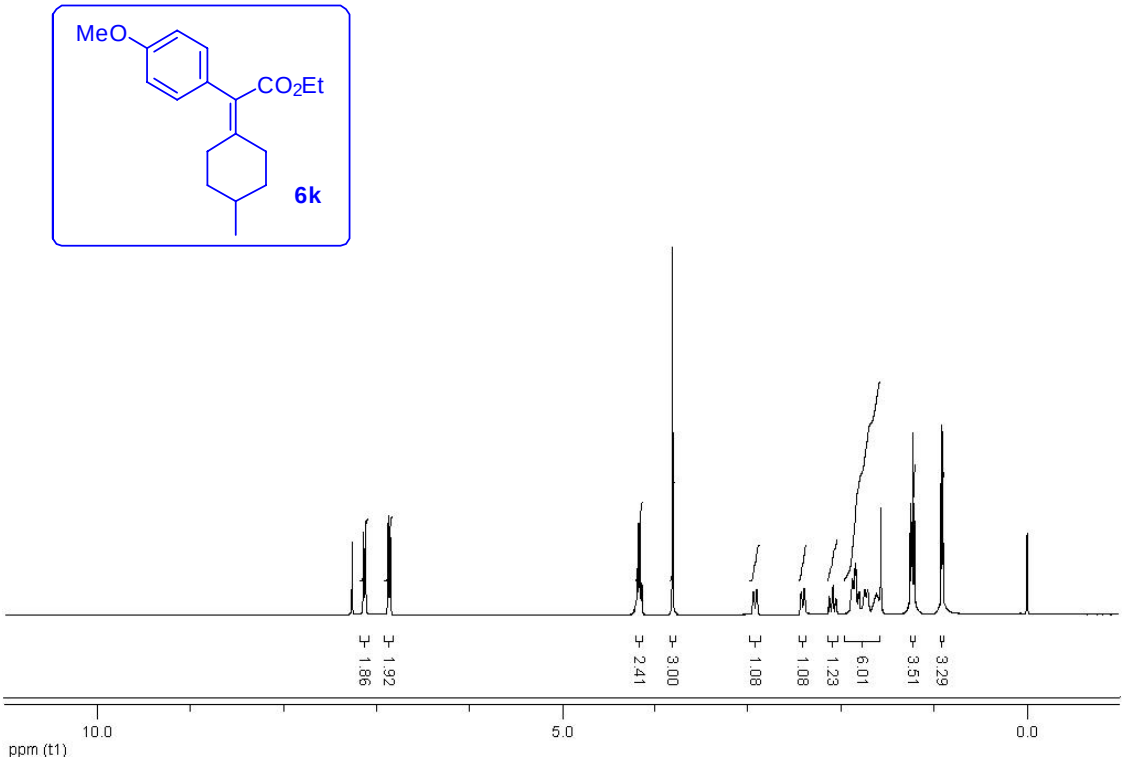
152.536
152.061
139.353
135.545
130.246
126.912
125.122
113.347
77.493
77.175
76.857
60.897
56.689
32.658
28.371
26.372
14.316
MeO
NO2
CO2Et
6j
200
150
100
50
0
ppm (f1)


MeO
CO2Et
6k
1.86
1.92
2.41
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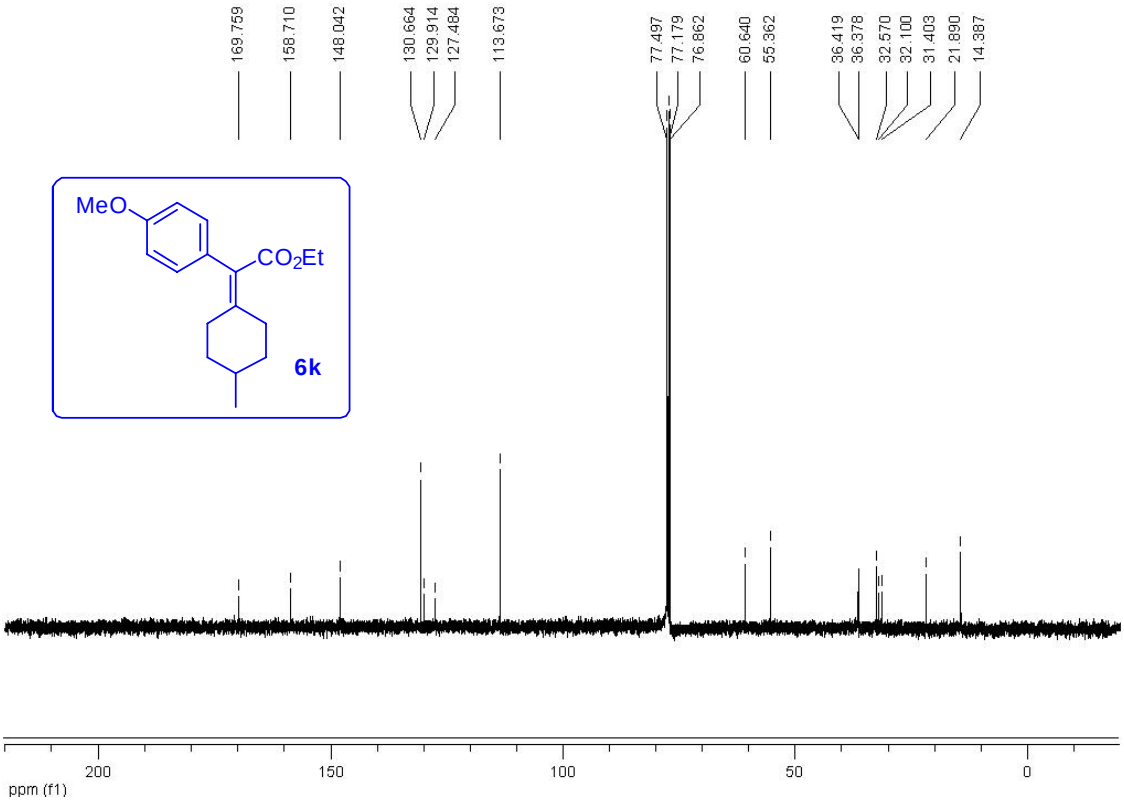
1.08
1.08
1.23
6.01
3.51
3.29
10.0
5.0
0.0
ppm (t1)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127.484
113.673
77.497
77.179
76.862
60.640
55.362
36.419
36.378
32.570
32.100
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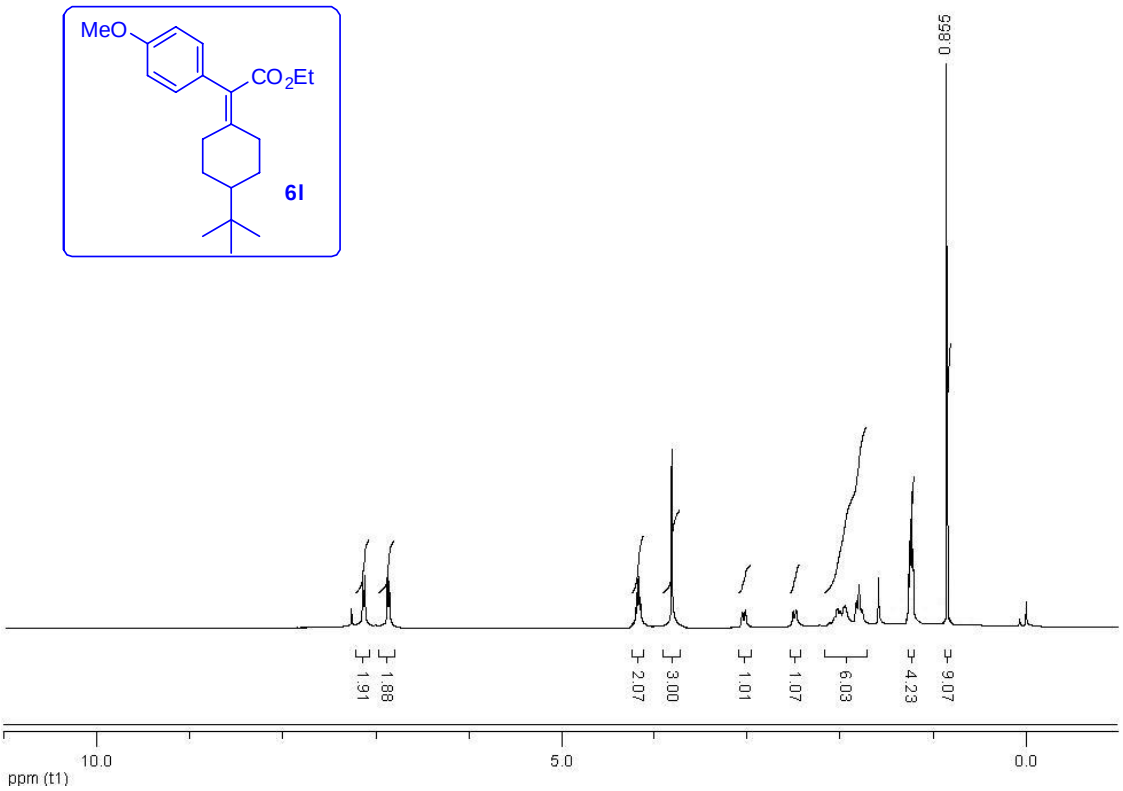
21.890
14.387
MeO
CO2Et
6k
200
150
100
50
0
ppm (f1)


MeO
CO2Et
6l
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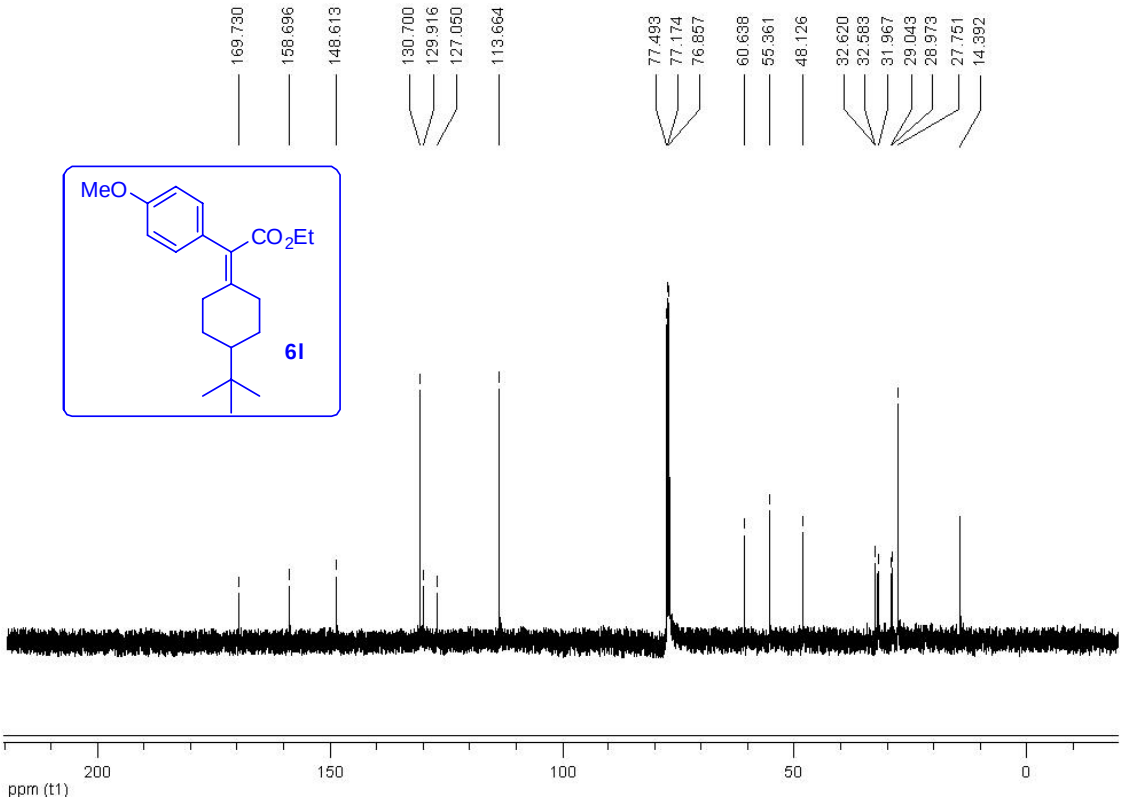
1.91
1.88
2.07
3.00
1.01
1.07
9.03
4.23
9.07
10.0
5.0
0.0
ppm (t1)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148.613
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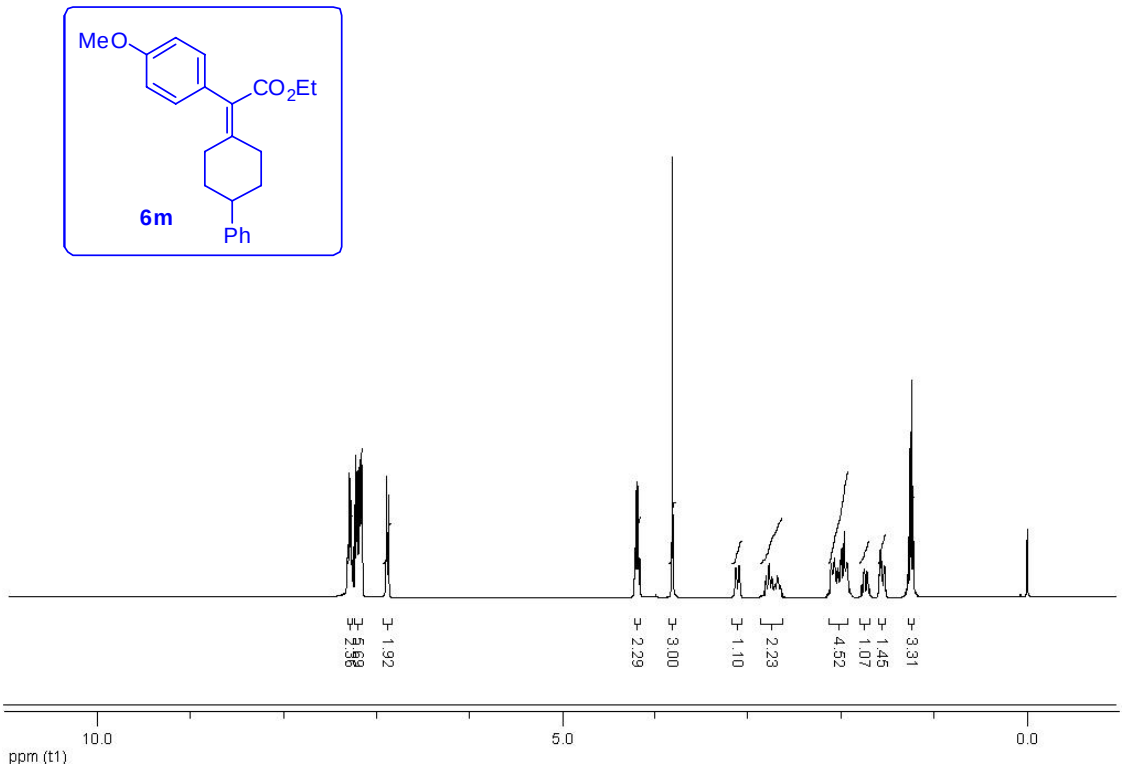
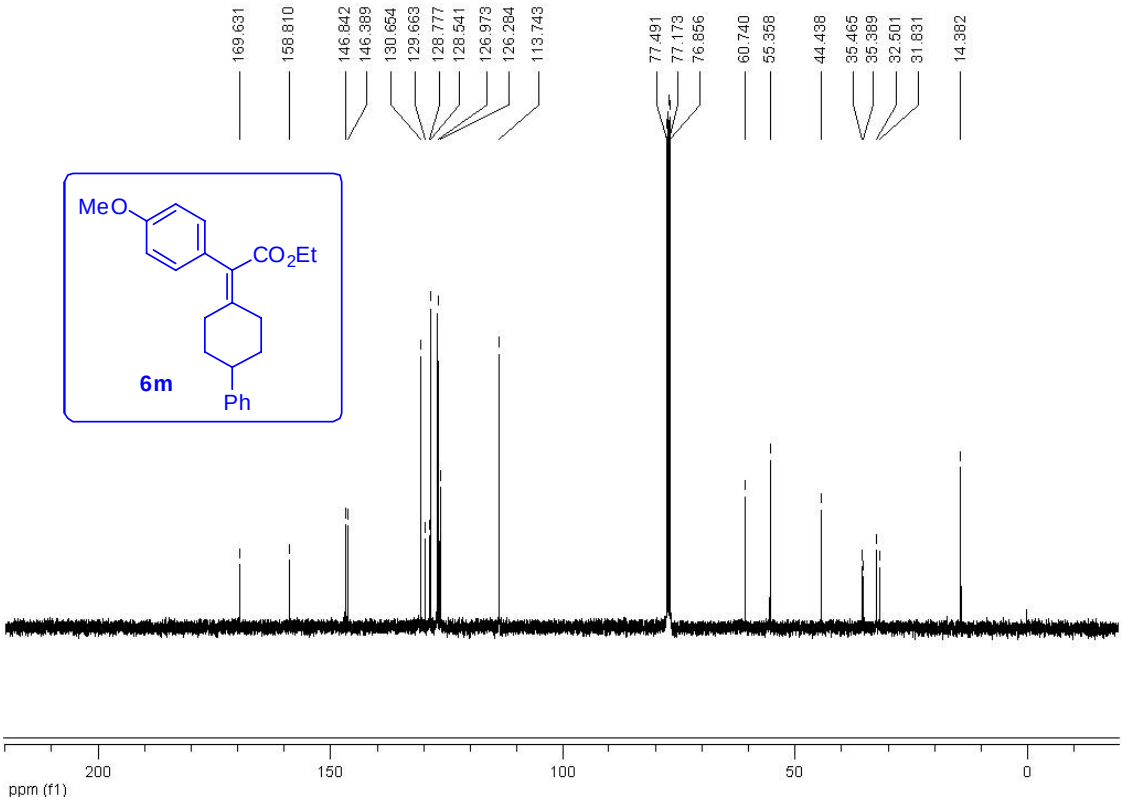
129.916
127.050
113.664
77.493
77.174
76.857
60.638
55.361
48.126
32.620
32.583
31.967
29.043
28.973
27.751
14.392
MeO
CO2Et
6l
200
150
100
50
0
ppm (t1)


MeO
CO2Et
6m
Ph
1.92
2.29
3.00
1.10
2.23
4.52
1.07
1.45
3.31
10.0
5.0
0.0
ppm (t1)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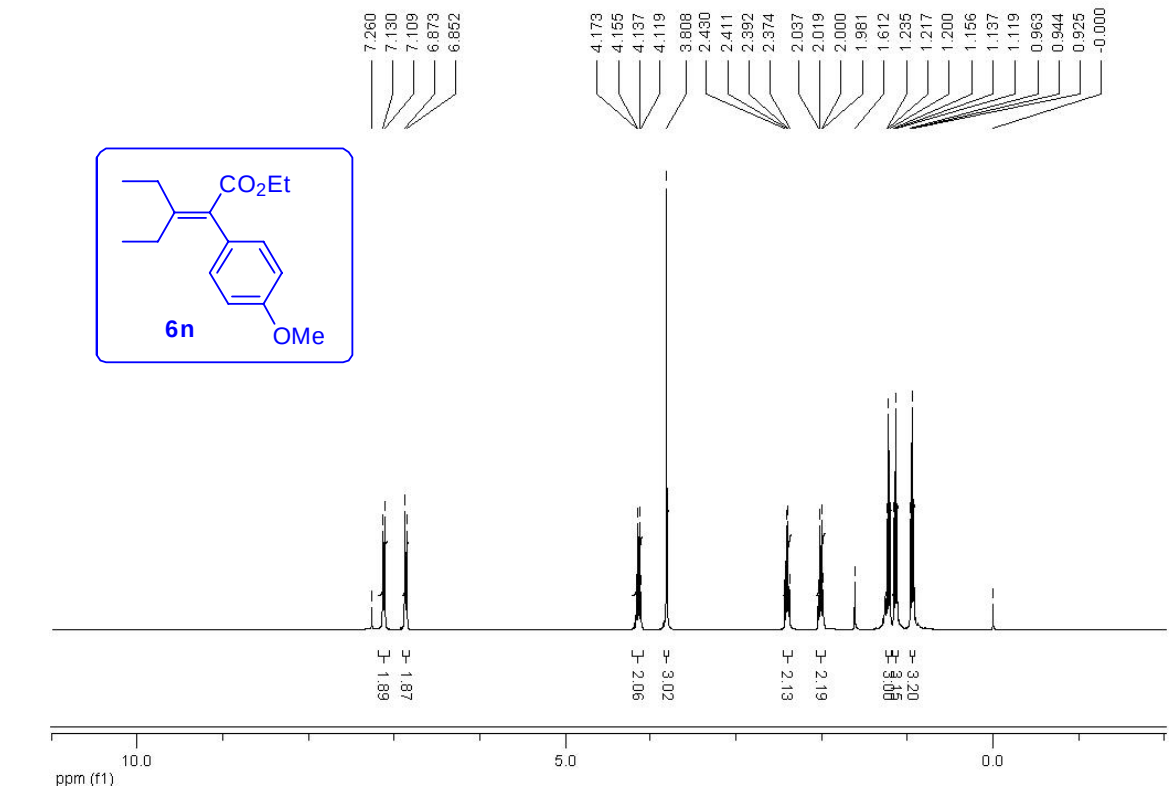
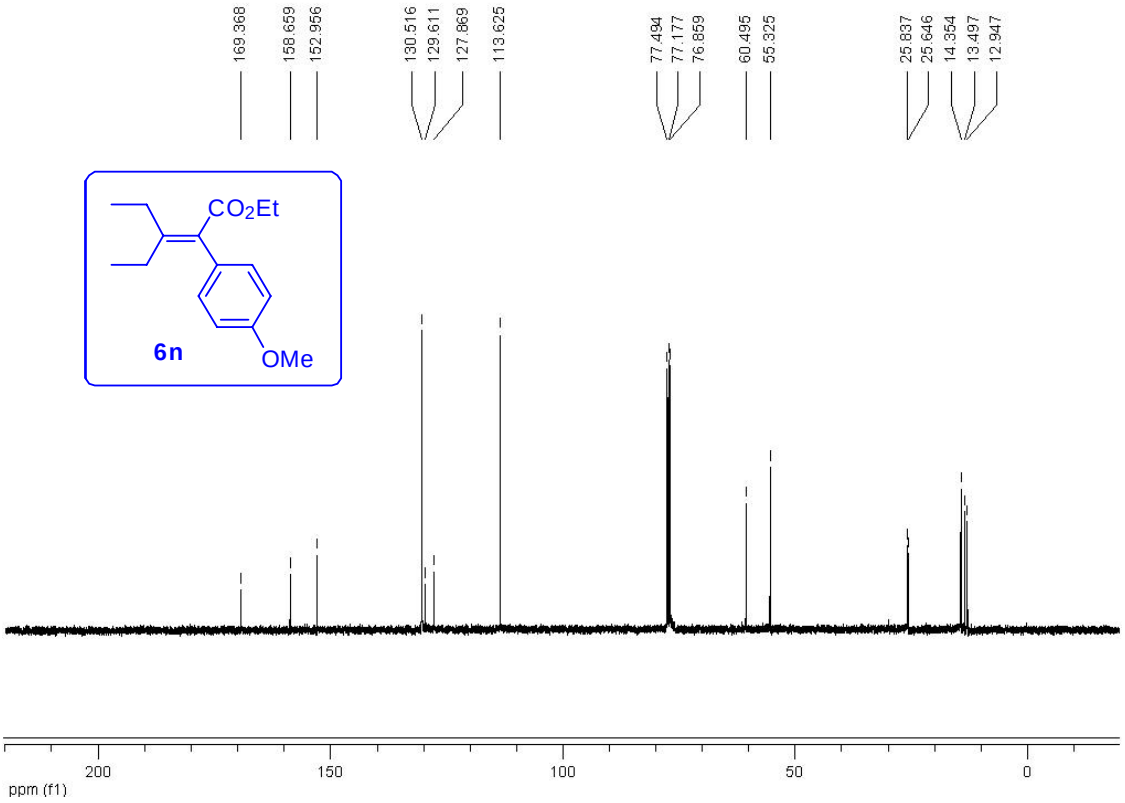
146.842
146.389
130.654
129.663
128.777
128.541
126.973
126.284
113.743
77.491
77.173
76.856
60.740
55.358
44.438
35.465
35.389
32.501
31.831
14.382
MeO
CO2Et
6m
Ph
200
150
100
50
0
ppm (f1)


7.260
7.130
7.109
6.873
6.852
4.173
4.155
4.137
4.119
3.808
2.430
2.411
2.392
2.374
2.037
2.019
2.000
1.981
1.612
1.235
1.217
1.200
1.156
1.137
1.119
0.963
0.944
0.925
-0.000
CO2Et
6n
OMe
1.89
1.87
2.06
3.02
2.13
2.19
3.05
3.20
10.0
5.0
0.0
ppm (f1)


169.368
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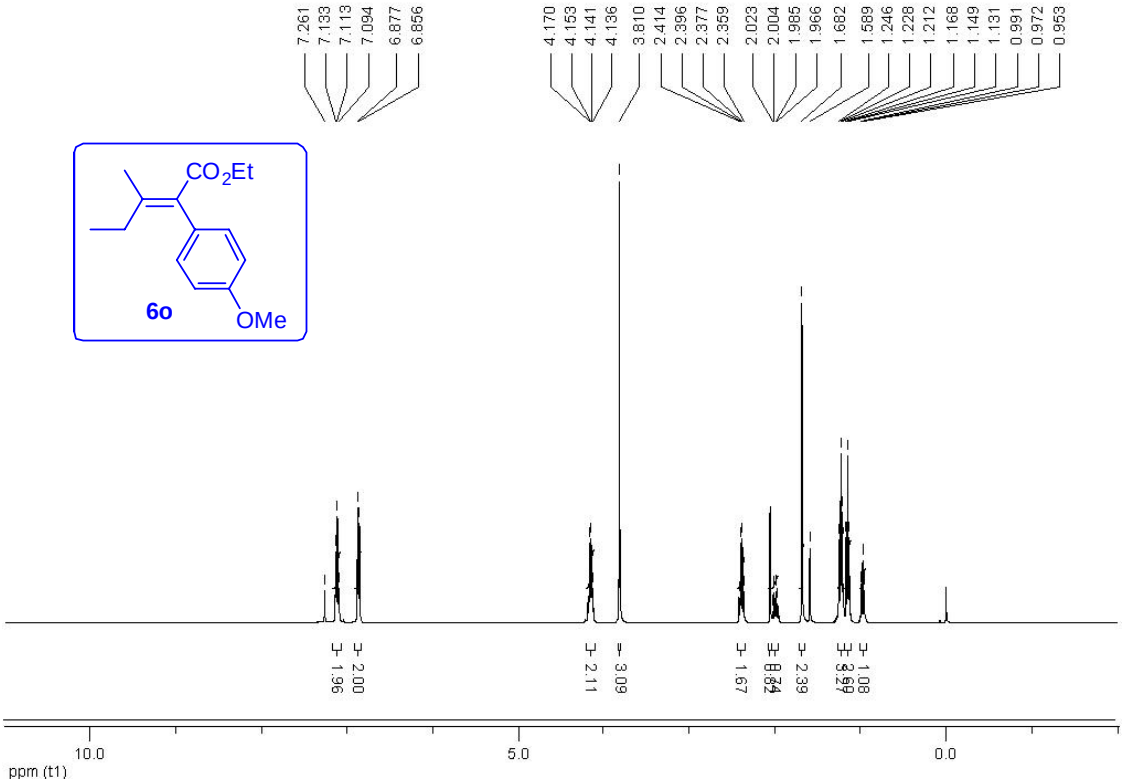
130.516
129.611
127.869
113.625
77.494
77.177
76.859
60.495
55.325
25.837
25.646
14.354
13.497
12.947
CO2Et
6n
OMe
200
150
100
50
0
ppm (f1)


7.261
7.133
7.113
7.094
6.877
6.856
4.170
4.153
4.141
4.136
3.810
2.414
2.396
2.377
2.359
2.023
2.004
1.985
1.966
1.682
1.589
1.246
1.228
1.212
1.168
1.149
1.131
0.991
0.972
0.953
CO2Et
6o
OMe
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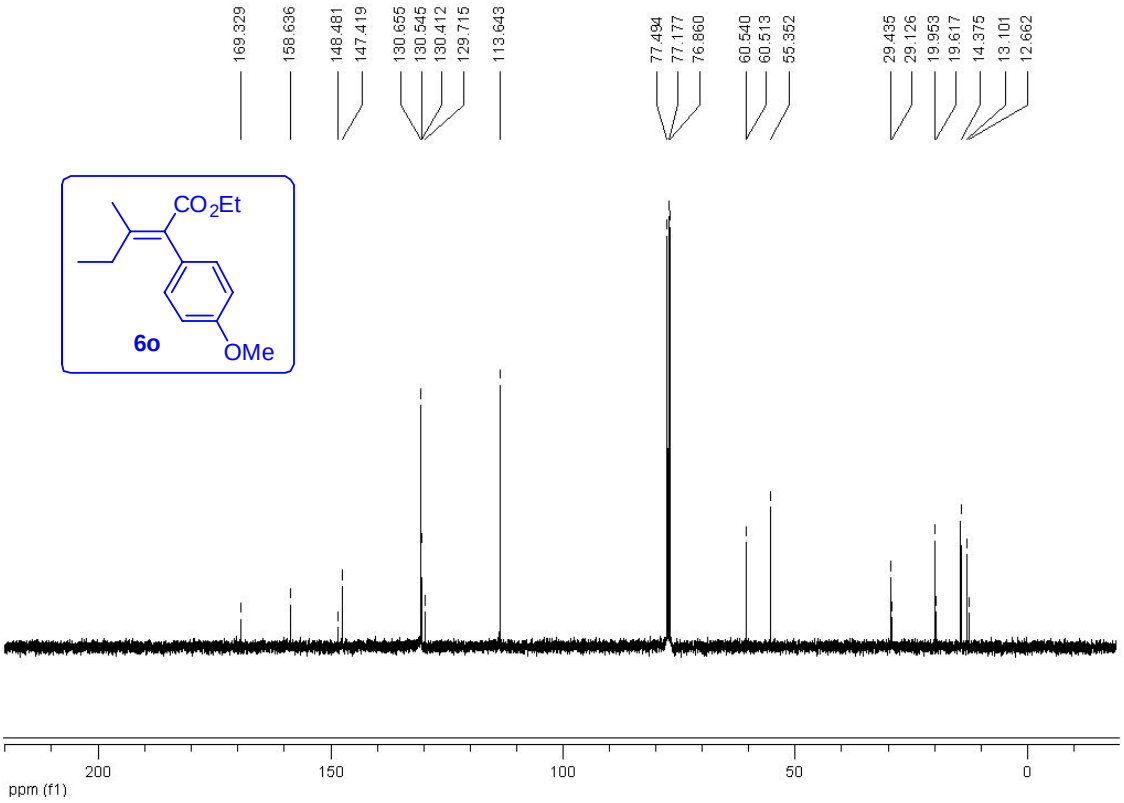
2.00
2.11
3.09
1.97
2.39
1.08
10.0
5.0
0.0
ppm (t1)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158.636
148.481
147.419
130.655
130.545
130.412
129.715
113.643
77.494
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60.540
60.513
55.352
29.435
29.126
19.953
19.617
14.375
13.101
12.662
CO2Et
6o
OMe
200
150
100
50
0
ppm (f1)